METROPOLITAN DISTRICT COMMISSION

DIVISION OF WATERSHED MANAGEMENT

WATER QUALITY REPORT: 2000

WACHUSETT RESERVOIR AND WATERSHED

ENVIRONMENTAL QUALITY SECTION

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WACHUSETT RESERVOIR

2000 WATER QUALITY DATA

CHEMICAL, PHYSICAL, BACTERIAL

PARAMETER	**REPORTING UNITS**
Temperature	degrees Centigrade
Depth	meters
Dissolved Oxygen	mg/L
Conductivity	μmhos/cm
Turbidity	nephelometric units
pH	units
Standard Alkalinity	mg/L as $CaCO_3$
EPA Alkalinity	mg/L as $CaCO_3$
Nitrate-Nitrogen	mg/L
Ammonia-Nitrogen	mg/L
Total Kjeldahl Nitrogen	mg/L
Silica	mg/L
Total Phosphorus	mg/L
Fecal Coliform	colonies/100mL

WACHUSETT RESERVOIR

2000 PHYTOPLANKTON DATA

PARAMETER	**REPORTING UNITS**
Algae Concentration	Areal Standard Units per mL

WACHUSETT RESERVOIR WATERSHED

2000 TRIBUTARY WATER QUALITY DATA

CHEMICAL, PHYSICAL, BACTERIAL

PARAMETER	**REPORTING UNITS**
Temperature	degrees Centigrade
Depth	feet
Flow	cubic feet per second
Conductivity	µmhos/cm
pH	units
Nitrate-Nitrogen	mg/L
Ammonia-Nitrogen	mg/L
Total Phosphorus	mg/L
Fecal Coliform	colonies/100mL

WATER QUALITY REPORT: 2000
WACHUSETT RESERVOIR AND WATERSHED

1.0 INTRODUCTION

The Metropolitan District Commission Division of Watershed Management was established by Chapter 372 of the Acts of 1984. The Division was created to manage and maintain a system of watersheds and reservoirs and provide pure water to the Massachusetts Water Resources Authority (MWRA), which in turn supplies drinking water to approximately 2.5 million people in forty-six communities.

Water quality sampling and watershed monitoring make up an important part of the overall mission of the Division. These activities are carried out by Environmental Quality Section staff at Wachusett Reservoir in West Boylston and at Quabbin Reservoir in Belchertown. This report is a summary of 2000 water quality data from the Wachusett watershed. A report summarizing 2000 water quality data from the Quabbin and Ware River watersheds is also available from the Division.

The Surface Water Treatment Rule requires filtration of all surface water supplies unless several criteria are met, including the development and implementation of a detailed watershed protection plan. The Division and the MWRA currently have a joint waiver from the filtration requirement and continue to aggressively manage the watershed in order to maintain this waiver. Water quality sampling and field inspections help identify tributaries with water quality problems, aid in the implementation of the Division's watershed protection plan, and ensure compliance with state and federal water quality criteria for public drinking water supply sources. Bacterial monitoring of the reservoir and its tributaries provide an indication of sanitary quality and help to protect public health. The Division also samples to better understand the responses of the reservoir and its tributaries to a variety of physical, chemical, and biological inputs, and to assess the ecological health of the reservoir and the watershed.

Routine water quality samples were collected from forty-six stations on thirty-five tributaries and from four stations on the reservoir. Algal populations in the Wachusett Reservoir were monitored weekly at the Cosgrove Intake and quarterly at three additional stations in order to detect increasing concentrations (blooms) and potential taste and odor problems, and to recommend copper sulfate treatment when necessary. Fecal coliform samples were collected from the reservoir surface, documenting the relationship between seasonal bacteria variations and roosting populations of gulls and geese on the reservoir as well as the impact of harassment on both birds and bacteria concentrations.

The 2000 pathogen sampling program continued to focus on the development of baseline data in order to provide the MDC with information on seasonal occurrence of *Giardia* and *Cryptosporidium*. Samples were collected twice per month from February through December at two stations on the major tributaries to the reservoir (the Quinapoxet and Stillwater Rivers). Results of this sampling program are included in this report.

The Pinecroft Area drainage basin is being investigated to evaluate the impacts of sewering on water quality in a small urbanized tributary to the Wachusett Reservoir. Initial sampling established baseline and stormwater nutrient and bacteria levels and profiled water quality within a small urbanized subbasin at the headwaters of Gates Brook prior to sewer construction. Two additional sampling locations were added in 1997, one in a pristine forested watershed and one at an agricultural operation. This enables the Division to compare and contrast urbanized conditions with those from pristine and agricultural sites.

Weekly sampling of the Pinecroft neighborhood continued in 2000 during the installation of sewers. Weekly samples were also collected from the agricultural and pristine sampling stations when flow was present. Data collected as part of this study are included in this report. A complete analysis will be published separately after several more years of data collection and interpretation.

Environmental Quality staff continued to monitor site-specific impacts of development on water quality. Ongoing communications with state and local officials helped ensure implementation of best management practices, remediation of existing problems, and quick notification of imminent threats. Staff attended conservation commission and board of health meetings monthly to provide technical assistance and to gain advance knowledge of proposed activities.

2.0 WATERSHED SAMPLING PROGRAM DESCRIPTION

Wachusett Environmental Quality staff collected routine water quality samples from forty-six stations on thirty-five tributaries and from four stations on the reservoir during 2000. The stations are described below in Table 1 and are located on Figure 1. The stations sampled included almost all tributaries sampled during the previous ten years. Additional stations were sampled intermittently to support special studies or potential enforcement actions. Nearly 5,000 samples were collected for in-house analysis; approximately 4,000 bacteria samples, 300 algae samples, and 350 chemical samples. Over 4,000 physiochemical measurements were done in the field. In addition, approximately 1000 samples were collected and sent to outside laboratories for the analysis of nutrients and pathogenic protozoa.

Each tributary station was visited weekly throughout the year. Temperature and conductivity were measured in the field using a YSI 30 conductivity meter and samples were collected for fecal coliform analysis. All analyses were done at the MDC lab facility in John Augustus Hall in West Boylston. Monthly samples for nitrate-nitrogen, nitrite-nitrogen, ammonia, silica, total phosphorus, UV-254, total suspended solids, and total organic carbon were collected from thirteen stations on eleven tributaries and analyzed by the MWRA Lab at Deer Island. Depth measurements were done at these stations to calculate flow using previously established rating curves. All sample collections and analyses were conducted according to Standard Methods for the Examination of Water and Wastewater 20th Ed. (Table 2).

Monthly temperature, dissolved oxygen, pH, and conductivity profiles were taken at four reservoir stations (Station 3409/Cosgrove Intake, Station 3417/Basin North, Station 3412/Basin South, and Thomas Basin) using a Hydrolab Surveyor III. Samples for nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, silica, alkalinity, and total phosphorus were collected in the epilimnion, metalimnion, and hypolimnion monthly during thermal stratification and at two depths (surface and bottom) during isothermal conditions. All parameters were analyzed by the MWRA Lab at Deer Island.

Fecal coliform samples were collected daily (Monday - Thursday) from the surface at the Cosgrove Intake to ensure compliance with federal regulations and to help monitor the effect of weather conditions, tributary inputs, and migratory gull and geese populations on bacteria concentrations. Samples were collected seven days per week during January and December when bird numbers were elevated. Fecal coliform samples were also collected monthly, biweekly, or weekly at numerous locations on the reservoir surface, documenting the relationship between seasonal bacteria variations and roosting populations of gulls and geese on the reservoir as well as the impact of harassment on both birds and bacteria concentrations. A sampling grid established eight years earlier with twenty-three sampling locations based on reservoir configuration and flow paths was again utilized. Sample locations are indicated on Figure 2.

TABLE 1

2000 WACHUSETT SAMPLING STATIONS

STATION	LOCATION	FREQUENCY
1. Airport Brook	Greenland Road, Sterling	W
2. Asnebumskit Bk (Mill St)	Mill Street, Holden	W
3. Asnebumskit Bk (Princeton St)	Princeton Street, Holden	W
4. Bailey Brook	Beaman Road, Sterling	W
5. Ball Brook	Route 140, Sterling	discontinued
6. Beaman Pond Brook	Off Route 110, W. Boylston	W
7. Boylston Brook	Route 70, Boylston	W
8. Chaffin Bk (Malden St)	Malden Street, Holden	W
9. Chaffin Bk (Unionville)	Unionville Pond outlet, Holden	W
10. Cold Brook	Mason Road, Holden	W
11. Cook Brook (Shrewsbury)	Shrewsbury Street, Holden	W, M
12. Cook Brook (Stoneleigh)	Stoneleigh Street, Holden	W, M
13. Cook Brook (Wyoming)	Wyoming Street, Holden	W, M
14. East Wachusett Brook (140)	Route 140, Sterling	W
15. East Wachusett Brook (31)	Route 31, Princeton	W
16. French Brook (70)	Route 70, Boylston	W, M
17. Gates Brook (1)	Gate 25, W.Boylston	W, M
18. Gates Brook (2)	Route 140, W.Boylston	W
19. Gates Brook (3)	Worcester Street, W.Boylston	W
20. Gates Brook (4)	Pierce Street, W.Boylston	W
21. Gates Brook (6)	Lombard Avenue, W.Boylston	W
22. Gates Brook (9)	Woodland Street, W.Boylston	W
23. Governor Brook	Sterling Road, Holden	W
24. Hastings Cove Brook	Route 70, Boylston	W
25. Houghton Brook	Route 140, Sterling	W
26. Jordan Farm Brook	Route 68, Rutland	W, M

W = weekly (bacteria, temperature, conductivity)
M = monthly (nutrients)

TABLE 1 (cont.)

2000 WACHUSETT SAMPLING STATIONS

STATION	LOCATION	FREQUENCY
27. Justice Brook	Route 140, Sterling	**W**
28. Keyes Brook	Gleason Road, Princeton	W
29. Landfill Brook	River Road, Holden	W
30. Malagasco Brook	West Temple Street, Boylston	W, M
31. Malden Brook	Thomas Street, W.Boylston	W, M
32. Muddy Brook	Route 140, W.Boylston	W, M
33. Oakdale Brook	Route 140, W.Boylston	W
34. Quabbin Aqueduct	below circular dam, W.Boylston	W
35. Quinapoxet River (dam)	above circular dam, W.Boylston	W, M
36. Rocky Brook (Beaman Rd)	Beaman Road, Sterling	W
37. Rocky Brook (East Branch)	Rowley Hill Road, Sterling	W, M
38. Scanlon Brook	Crowley Road, Sterling	W
39. Scarlett Brook	Worcester Street, W.Boylston	W
40. Stillwater River (sb)	Muddy Pond Road, Sterling	W, M
41. Swamp 15 Brook	Harris Street, Holden	W
42. Trout Brook	Manning Street, Holden	W
43. Unnamed Brook	Route 140, Sterling	W
44. Warren Tannery Brook	Quinapoxet Street, Holden	W
45. Waushacum Brook (Pr)	Prescott Street, W.Boylston	W
46. West Boylston Brook	Gate 25, W.Boylston	W, M
47. Wilder Brook	Wilder Road, Sterling	W
A. 3409 (Reservoir)	Cosgrove Intake	**D, W, M, Q**
B. 3417 (Reservoir)	mid reservoir by Cunningham Ledge	M, Q
C. 3412 (Reservoir)	mid reservoir southwest of narrows	M, Q
D. TB (Reservoir)	Thomas Basin	M, Q

D = daily (bacteria M-Th)
W = weekly (bacteria, temperature, conductivity, algae [Cosgrove])
M = monthly (nutrients [tributaries], profiles[reservoir])
Q = quarterly (algae, and nutrients [reservoir])

Figure 1.

SAMPLING STATIONS

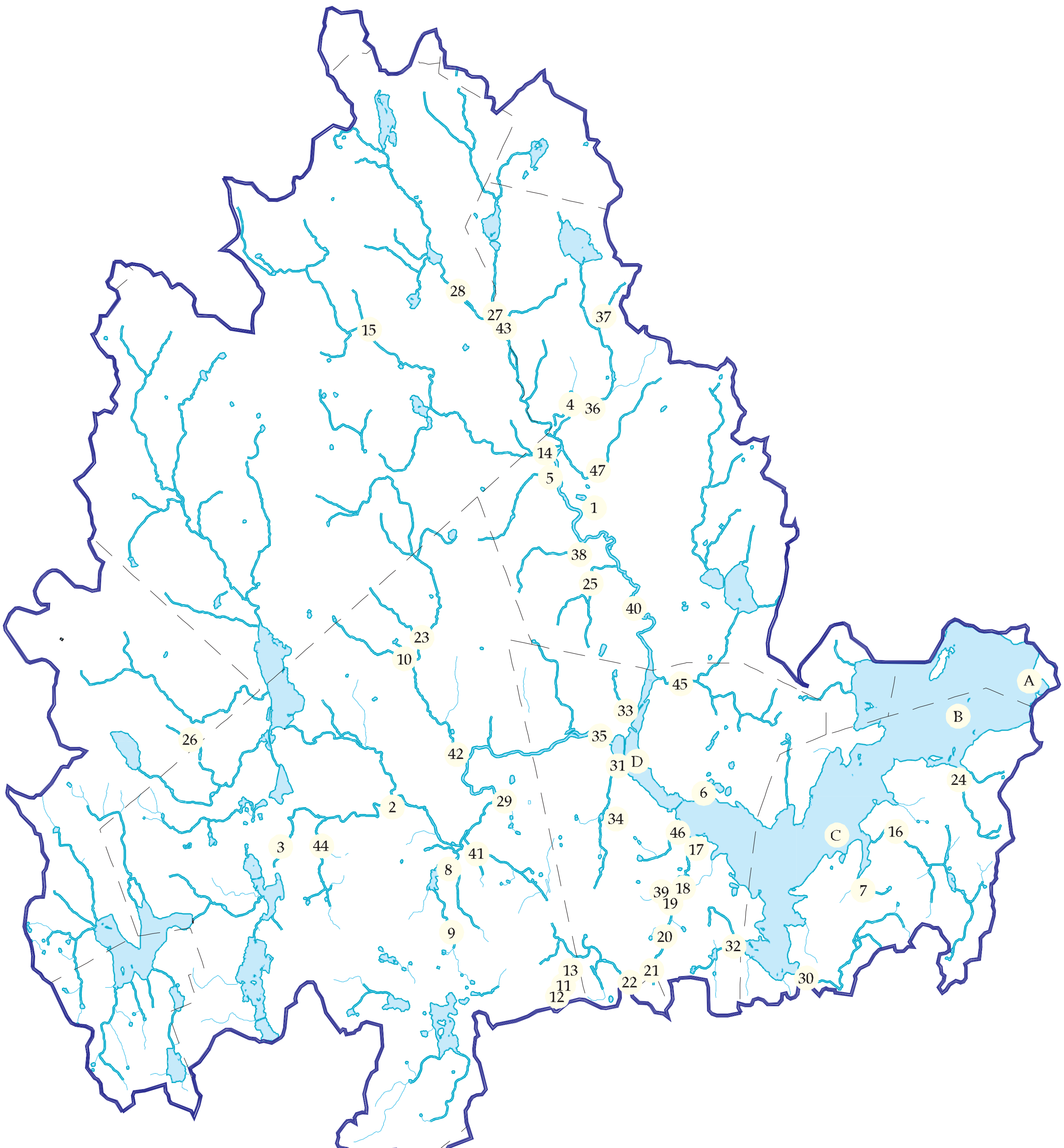


Figure 2.

RESERVOIR TRANSECT STATIONS

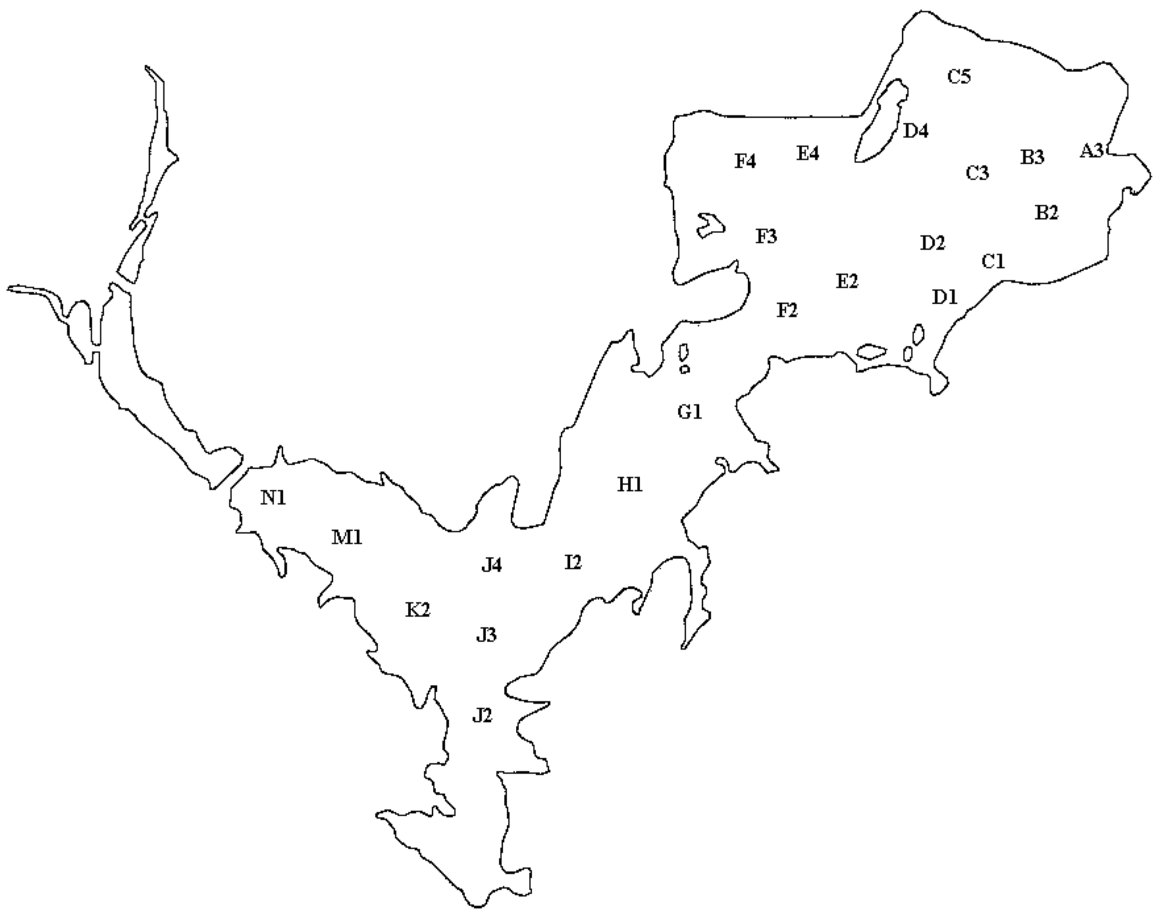


TABLE 2

METHODS USED FOR FIELD AND LABORATORY ANALYSIS WACHUSETT LABORATORY

PARAMETER	STANDARD METHOD
pH	Hydrolab Surveyor III
Conductivity	YSI Model 30 meter Hydrolab Surveyor III
Temperature	Hydrolab Surveyor III YSI Model 30 meter
Dissolved Oxygen	Hydrolab Surveyor III
Fecal Coliform	SM 9222 D
Algae	SM 10200 F

SM = Standard Methods for the Examination of Water and Wastewater - 20th edition, 1999

Algal populations in the Wachusett Reservoir were monitored at the Cosgrove Intake to detect increasing levels (blooms) and potential taste and odor problems, and to recommend copper sulfate treatment when necessary. Samples were collected once or twice weekly at six depths (0, 6, 8, 10, 12, and 14m) to help detect rapidly changing populations of golden-brown algae and other potential problem genera. Samples were collected quarterly from three additional stations to help improve the Division’s understanding of algal population dynamics throughout the entire reservoir.

Giardia and *Cryptosporidium* samples were collected once or twice monthly from February through December. Forty-two samples were collected from two stations on the Quinapoxet and Stillwater Rivers, the two largest tributaries to the reservoir. Baseline information on seasonal occurrence of these pathogens was gathered and added to an expanding database. Results of this sampling program are included in this report.

3.0 SUMMARY AND DISCUSSION OF RESULTS

3.1 TRIBUTARIES

All data collected were recorded in permanent laboratory books and also as part of an electronic database (Microsoft Excel files Tribs1-00.xls, Tribs2-00.xls, G-c2000.xls, and Nutrient-trib.xls) located at the MDC-DWM Water Quality Laboratory in West Boylston, Massachusetts. Results of tributary water quality testing are discussed by parameter in sections 3.1.1 - 3.1.7. All water quality data are included as appendices to this report.

3.1.1 BACTERIA

Fecal coliform were measured in the tributaries as an indicator of sanitary quality. Coliform density has been established as a significant measure of the degree of pollution and has been used as a basis of standards for bacteriological quality of water supplies for some time. Fecal coliform bacteria are found within the digestive system of warm-blooded animals and are almost always present in water containing pathogens. These bacteria are relatively easy to isolate in a laboratory. Water that is free of fecal coliform is generally considered to be free of disease-producing organisms.

Fecal coliform levels were measured weekly at all tributary stations. The Massachusetts Class A surface water quality standards established in 314 CMR 4.00 state that "fecal coliform bacteria shall not exceed an arithmetic mean of 20 colonies/100 mL in any representative set of samples, nor shall more than 10% of the samples exceed 100 colonies/100 mL". Using a yearly arithmetic mean, the standard of 20 colonies/100 mL was exceeded at 37 of 46 tributary stations. In most years 90% of all streams sampled have failed to meet this standard, so the nearly 20% success rate for 2000 should be seen as a positive sign. Similar results were noted in 1999. It should be noted that one or two high values can markedly elevate the annual mean of a relatively small data set, and fecal coliform values sometimes increase by several orders of magnitude following storm events or during periods of high groundwater. Two additional streams (Chaffins Brook at Unionville, Jordan Farm Brook) would have also met the standard if a single abnormally high sample was excluded from the calculation of yearly arithmetic mean. Three streams (Governor Brook, Landfill Brook, and Trout Brook) would meet the standard if two high values were excluded. Hastings Cove Brook and Keyes Brook met the standard until the final three weeks of 2000 when fecal coliform concentrations sharply increased. Hastings Cove Brook probably was impacted by the removal of a beaver dam upstream and subsequent flushing of contaminated sediments. It is not clear what caused the decline in water quality in Keyes Brook. It is clear, however, that a different way of looking at the data may give a better representation of actual conditions in these tributaries throughout the year. The use of median values as an alternative method to represent water quality was proposed several years ago by Environmental Quality staff. Table 3 includes both annual mean and annual median values for fecal coliform data in the tributaries. It is also apparent that storm events play a major role in fecal coliform loading and a more focused look at precipitation and fecal coliform will be done in 2001.

TABLE 3

FECAL COLIFORM - TRIBUTARIES
(colonies/100 mL)

STATION	MAX	MIN	MEAN	MEDIAN (2000)	MEDIAN (1999)	SAMPLES
Airport Brook	196	0	28	11	21	30
Asnebumskit (Mill)	640	0	61	20	19	50
Asnebumskit (Princeton)	9800	6	1070	231	465	46
Bailey Brook	97	0	8	1	1	50
Beaman Pond Brook	1110	1	207	51	21	20
Boylston Brook	200	0	35	19	12	47
Chaffin Bk. (Malden St)	5300	1	197	15*	31	49
Chaffin Bk. (Unionville)	14500	0	316	3*	5	49
Cold Brook	1100	0	49	3	5	50
Cook Bk. (Shrewsbury)	12000	0	590	46*	57	42
Cook Bk. (Stoneleigh)	13500	1	912	90*	210	35
Cook Bk. (Wyoming)	13400	0	408	18*	25	50
East Wachusett (140)	100	0	19	12	22	50
East Wachusett (31)	44	0	6	5	2	50
French Brook (70)	440	0	38*	10	10	36
Gates Brook (1)	44000	0	1369	25	19	49
Gates Brook (2)	38000	0	1416	43	61	49
Gates Brook (3)	7600	0	595	50	45	49
Gates Brook (4)	16800	4	913	46	79	49
Gates Brook (6)	11400	1	847	60	103	50
Gates Brook (9)	14600	0	500	35	47	50
Governor Brook	780	0	46	4	1	49
Hastings Cove Brook	2100	0	75	5	3	49
Houghton Brook	590	0	78	25	13	50
Jordan Farm Brook	2130	0	82*	6*	19	32
Justice Brook	15	0	2	2	2	50
Keyes Brook	500	0	26	10	15	50
Landfill Brook	1320	0	59	3	5	50
Malagasco Brook	1580	0	76	26	33	50
Malden Brook	280	0	30	10*	21	50
Muddy Brook	181	0	25	9	11	50
Oakdale Brook	880	0	137*	46*	64	50
Quabbin Aqueduct	48	0	2	0	0	31
Quinapoxet River (dam)	6100	0	201	16	15	50

*below historic levels

TABLE 3 (cont)

FECAL COLIFORM - TRIBUTARIES
(colonies/100 mL)

STATION	MAX	MIN	MEAN	MEDIAN (2000)	MEDIAN (1999)	SAMPLES
Rocky Bk. (Beaman Rd)	117	0	15*	5	10	50
Rocky Bk. (E. Branch)	132	0	9	0	0	36
Scanlon Brook	82	0	7*	2	1	50
Scarlett Brook	10200	0	521	40	12	48
Stillwater River (sb)	290	0	42	17	20	50
Swamp 15 Brook	6000	0	273	12*	21	49
Trout Brook	520	0	33	2*	3	50
Unnamed Brook	120	0	9	1	1	40
Warren Tannery Brook	450	0	50	13*	19	31
Waushacum Brook (Pr)	330	0	37	20	17	50
West Boylston Brook	64000	0	1860	40	37	49
Wilder Brook	720	1	83	23	8	24

*below historic levels

Samples collected at 21 of 46 sampling stations (46%) exceeded the standard of 100 colonies/100 mL on more than 10% of the sampling dates in 2000. This was better than in all previous years and continues the improving trend noted in the 1999 report. Five streams recorded their lowest ever annual mean, while eleven stations on eight tributaries recorded median values below historic levels (see Table 3). Twelve stations had annual mean values higher than all previous years, but all were sampled during several storm events throughout the year which had a strong negative impact on average values. None of the stations had median values above expected levels and in fact some of the stations with higher than normal annual means were the same ones with their lowest ever median values. This again points out the potential problem with the use of fecal coliform annual mean values to assess water quality in Wachusett tributaries.

When the tributaries are ranked using annual mean values, West Boylston Brook, Asnebumskit Brook (Princeton St), Cook Brook (Stoneleigh), and five stations on Gates Brook have the highest concentrations of fecal coliform, followed by Cook Brook (Shrewsbury) and Scarlett Brook. When they are ranked using median values, most of the ten worst remain the same, but the order is dramatically altered. The “worst” tributary using annual mean as the criteria is West Boylston Brook, but using median values this stream is only the tenth worst. Asnebumskit Brook (Princeton St) is the fourth worst based on annual mean, but it was unquestionably the worst when median values are compared. Beaman Pond Brook and Oakdale Brook would be considered “average” when annual means are compared, but both ranked among the six worst tributaries using median values. A close examination of the data show that many of the elevated mean values are the result of one or two storm-influenced samples containing between 10,000 and 64,000 colonies/100 mL. A ranking based on median values is believed to be a more accurate representation of actual water quality.

Determining the tributaries with the lowest concentrations of fecal coliform and therefore the best water quality was also a function of whether annual mean or annual median was used. Bailey Brook, East Wachusett Brook (Rt. 140 and Rt.31), Justice Brook, Quabbin Aqueduct, Rocky Brook (Beaman Road and East Branch), Scanlon Brook, and Unnamed Brook all met the Class A standard with an annual mean of less than 20 colonies/100 mL. They had very low annual median concentrations as well, ranging from 0 – 12 colonies/100 mL. Airport Brook, Chaffins Brook (Unionville), Cold Brook, French Brook, Governor Brook, Hastings Cove Brook, Jordan Farm Brook, Keyes Brook, Landfill Brook, Malden Brook, Muddy Brook, Swamp 15 Brook, and Trout Brook also had very low annual median concentrations, comparable to the nine stations that met the Class A standard, but had elevated annual mean values probably related to a few significant storm events. This suggests that overall water quality in Wachusett tributaries may be considerably better than previously indicated.

Multiple sampling stations on Gates Brook were examined to help locate sources or suspected sources of fecal contamination. Gates Brook remains one of the most contaminated tributaries in the watershed, regardless of whether mean or median values are used. The results from the six stations were quite variable, although Gates 6 had an annual median higher than the other five stations. Samples collected from Gates 6 had the highest count from this tributary on only nine days, scattered throughout the year. Samples from Gates 3 had the highest value on 14 of 50 days, but nearly half occurred during the first three months of the year when concentrations at all sampling stations were generally below 100 colonies/100mL. The maximum value recorded was 44,000 colonies/100mL from Gates 1 in August. Similar mixed results were obtained from these stations in 1995, 1996, 1997, 1998, and 1999, which seems to confirm that multiple sources of fecal coliform still exist. Environmental Quality staff will continue to search for specific sources such as failing septic systems, stormwater discharge pipes, or animal populations and will initiate remedial actions wherever possible. It is expected that sewers will significantly improve water quality in the near future once installation and connections are completed.

Stations on Cook Brook had a level of contamination much lower than in the past, presumably the result of sewer installation and hookups. The highest concentrations of fecal coliform in this brook were again recorded at the station on Stoneleigh Street. Further improvements in 2001 are expected.

Median fecal coliform concentrations in 2000 were similar to those measured in 1999, although improvements were noted at eleven stations. Six of these stations (Chaffin Brook (Malden Street), Cook Brook (Stoneleigh Street), Jordan Farm Brook, Malden Brook, Oakdale Brook, and Swamp 15 Brook) had median concentrations lower than previously recorded. Four tributaries (Wilder Brook, Scarlett Brook, Houghton Brook, and Beaman Pond Brook) had higher median concentrations than in 1999, but still well within the range of annual median values recorded over the last thirteen years.

Although annual statistics are useful in determining trends in water quality, it has become clear that they also miss a great deal of information and in fact can provide an inaccurate assessment of overall water quality. Problems with relying on annual mean fecal coliform numbers have been illustrated throughout this section. While annual median values are a better representation of what has occurred during the year, it appears that a closer examination of the raw data is warranted. A preliminary assessment found significant differences in water quality at different times of the year, presumably related to groundwater elevations, frequency of precipitation events, stream flow, and impacts of temperature on the survival of fecal coliform bacteria. Twenty-seven of forty-six stations sampled during the first quarter of 2000 had samples containing less than the limit of 20 colonies/100 mL at least 80% of the time. Only eleven stations met this criteria during the second quarter, and during the third quarter it declined to five of forty-six. Sixteen of forty-four stations (two were dry) met the criteria during the final three months of the year. The 2001 sampling program will attempt to address some of these seasonal differences by comparing dry weather samples without including samples impacted by storm events. A separate stormwater sampling program including all routinely sampled tributaries will also be part of the regular sampling program in order to help quantify bacterial loading to the reservoir from storm events. Tributary sampling will take place immediately following rain events (first flush) and then all stations will be resampled after 24 and 48 hours to see how long elevated fecal coliform concentrations persist after a storm. Precipitation amounts, groundwater levels, and stream flows will all be carefully documented and compared to bacteria numbers to attempt to further refine our understanding of the causes of elevated fecal coliform levels in Wachusett tributaries.

3.1.2 NUTRIENTS

Monthly grab samples for nitrate-nitrogen, nitrite-nitrogen, ammonia, silica, total phosphorus, total suspended solids, total organic carbon, and UV-254 were collected from thirteen stations on eleven tributaries to document nutrient loading to the reservoir. Samples for nitrate-nitrogen, nitrite-nitrogen, and ammonia were filtered in the field using a 1 micron glass fiber Acrodisc and then frozen; samples for total phosphorus were simply frozen. Samples for the other parameters were preserved as necessary according to standard methods. Flow measurements were determined each month using staff gages and USGS rating curves. Samples were delivered regularly to the MWRA lab at Deer Island and analyzed using methods with low detection limits. All data collected are included in an appendix to this report and are discussed in the following section.

Nitrate-nitrogen concentrations measured in the eight routine tributaries (excluding the "Pinecroft Study" stations) ranged from below the detection limit of 0.005 mg/L NO_3-N to 4.19 mg/L NO_3-N. Nitrate levels have historically been highest in West Boylston Brook and are usually significantly elevated with respect to the other tributaries and the reservoir. This remained true in 2000. The mean annual nitrate-nitrogen concentration in West Boylston Brook was between four and thirty times higher than those measured in all other tributaries with the exception of Gates Brook. Elevated nitrate levels in these two brooks are expected because of the high number of improperly functioning septic systems and the density of development in their subwatersheds.

TABLE 4

NITRATE-NITROGEN CONCENTRATIONS (mg/L)

station	FRENCH	MALAGASCO	MUDDY	GATES	W.BOYLSTON	MALDEN	QUINAPOXET	STILLWATER
MAX	0.275	0.956	0.202	2.45	4.19	1.53	0.662	0.367
MIN	<0.005	0.338	0.069	0.95	1.60	0.324	0.016	0.085
MEAN	0.100	0.689	0.136	1.83	3.18	0.637	0.324	0.185
MED	0.065	0.735	0.136	1.92	3.33	0.604	0.314	0.151

Nitrate-nitrogen concentrations were fairly uniform throughout the year in most tributaries with a few exceptions. Concentrations were higher during the spring and summer in Malagasco Brook. A similar phenomenon was noted in 1999. There was also a sharp unexplained increase in concentrations measured in December in more than half of the tributaries sampled (see Figures 3 and 4).

Figure 3

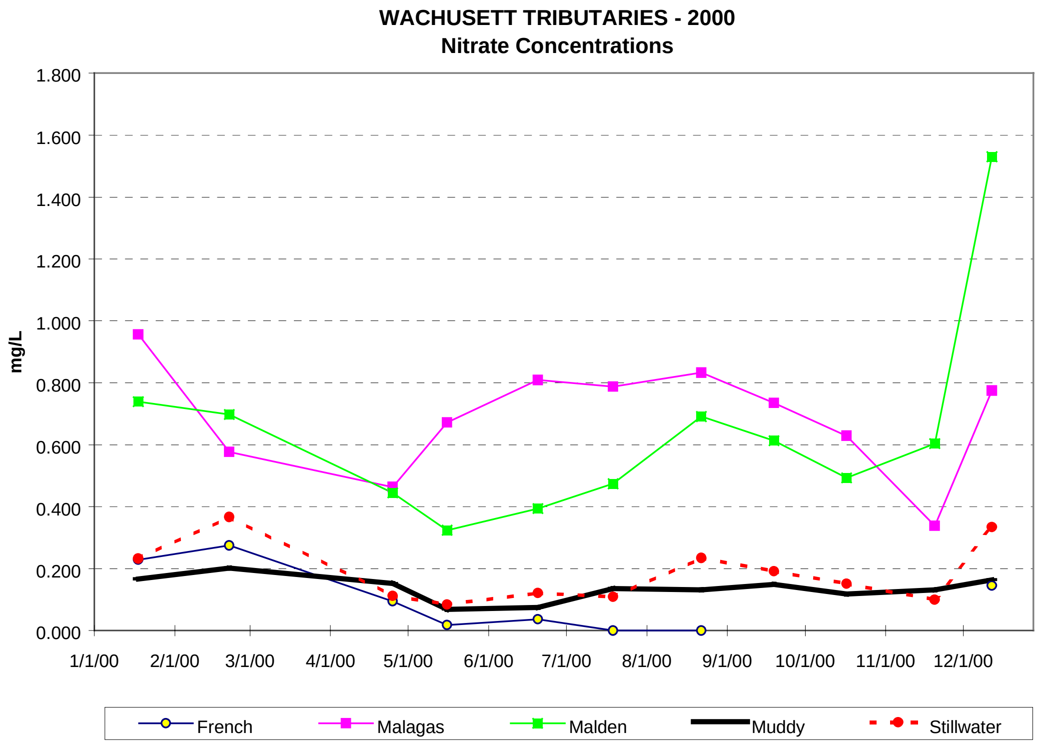
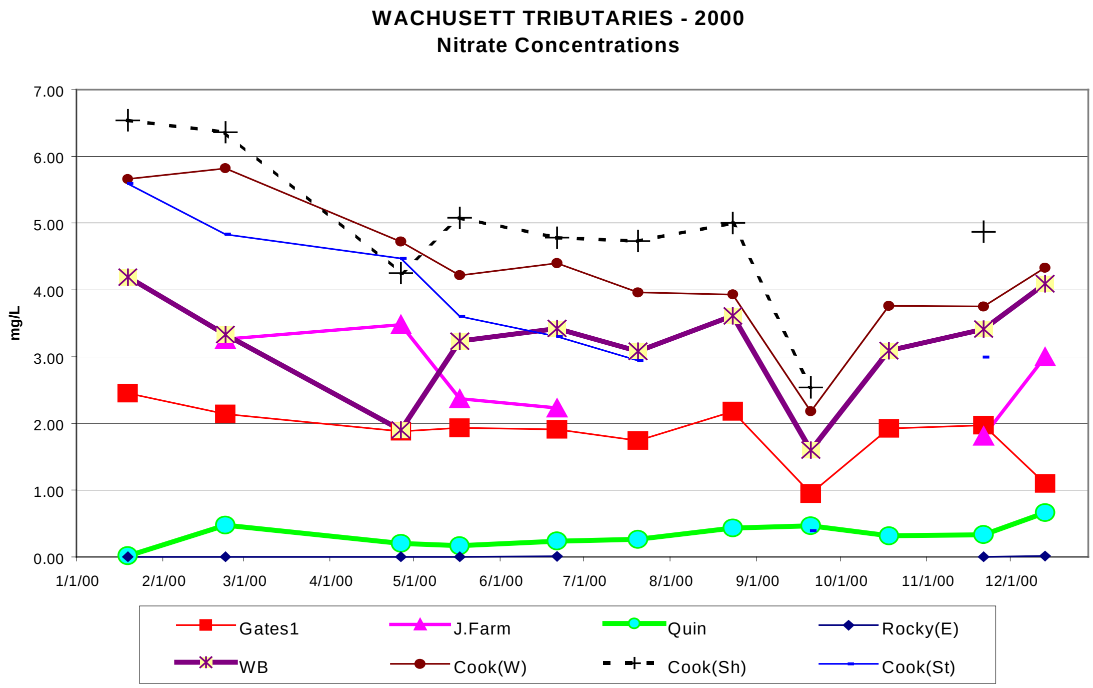


Figure 4



Concentrations were higher at three Cook Brook stations, with a maximum value of 6.54 mg/L NO_3-N. Annual mean concentrations were 10-50% higher than those measured in West Boylston Brook. Samples collected from Jordan Farm Brook had concentrations comparable to West Boylston Brook and Gates Brook samples. Nitrate-nitrogen was only detected in twenty-eight percent of samples collected from Rocky Brook (East Branch), even using a low detection limit of 0.005 mg/L.

TABLE 5

NITRATE-NITROGEN CONCENTRATIONS (mg/L)

station	COOK (Stoneleigh)	COOK (Shrewsbury)	COOK (Wyoming)	JORDAN FARM	ROCKY (East)
LANDUSE	[residential]	[residential]	[residential]	[agriculture]	[undeveloped]
MAX	5.59	6.54	5.82	3.48	0.011
MIN	0.39	2.54	2.18	1.81	<0.005
MEAN	3.51	4.91	4.25	2.69	0.004
MED	3.45	4.87	4.22	2.68	<0.005

Nitrate data from the three tributaries in the Pinecroft study continue to illustrate significant differences caused by different land uses (see Table 5 on previous page). Concentrations were highest in samples from the stream in a high density residential watershed with on-site wastewater treatment (Cook Brook). Annual mean and median values for Cook Brook were 30-80% higher than those recorded from Jordan Farm Brook, which has a watershed dominated by agricultural landuse. Samples from Rocky Brook (East Branch) contained very low concentrations of nitrate-nitrogen. This tributary is in a forested watershed with almost no development at all.

Annual mean and median nitrate-nitrogen concentrations seen in all tributaries during 2000 were comparable to those recorded during 1999, although slightly higher in most cases. All fell within historic ranges except for Muddy Brook. For the second year in a row, this tributary recorded an annual average and median lower than had been previously measured.

Nitrite-nitrogen was detected at very low concentrations, with a maximum value of 0.024 mg/L measured in June at the Cook Brook (Stoneleigh) station. Most samples, including all samples from French Brook, Gates Brook, West Boylston Brook, Jordan Farm Brook and Rocky Brook (East Branch) had concentrations below the limits of detection (0.005 mg/L). Ammonia was detected at considerably higher concentrations, especially at two of the three Cook Brook stations, and at French and Muddy Brooks. All but one of the samples collected from the Stoneleigh and Shrewsbury stations contained measurable levels of ammonia, with a maximum value of 0.285 mg/L at Cook Brook (Stoneleigh) in January. The surrounding neighborhood has numerous problems with failing septic systems and is an obvious source. Samples from Cook Brook (Wyoming) had much lower concentrations of ammonia, presumably because this downstream station was at a greater distance from failing septic systems than were the other two stations. Detectable levels of ammonia were only found in two of eleven samples from Cook Brook (Wyoming). Beaver probably impacted samples from French Brook, but the persistent presence of elevated concentrations of ammonia in Muddy Brook is as yet unexplained. Almost no ammonia was detected in either Malden or Gates Brooks, and none was found in samples from Jordan Farm Brook or Rocky Brook (East Branch).

TABLE 6

AMMONIA-NITROGEN CONCENTRATIONS (mg/L)

station	FRENCH	MALAGASCO	MUDDY	GATES	W.BOYLSTON	MALDEN	QUINAPOXET	STILLWATER
MAX	0.131	0.063	0.073	0.013	0.029	0.015	0.081	0.034
MIN	<0.005	0.006	0.006	<0.005	1.60	<0.005	<0.005	<0.005
MEAN	0.042	0.022	0.032	0.006	0.016	0.007	0.017	0.015
MED	0.031	0.019	0.020	0.005	0.012	0.007	0.010	0.015

TABLE 6 (cont.)

AMMONIA-NITROGEN CONCENTRATIONS (mg/L)

station	COOK (Stoneleigh)	COOK (Shrewsbury)	COOK (Wyoming)	JORDAN FARM	ROCKY (East)
LANDUSE	residential [upstream]	residential [midstream]	residential [downstream]	agriculture	undeveloped
MAX	0.285	0.123	0.045	<0.005	<0.005
MIN	0.001	<0.005	<0.005	<0.005	<0.005
MEAN	0.089	0.046	0.007	<0.005	<0.005
MED	0.072	0.032	<0.005	<0.005	<0.005

A potential source of the ammonia in Muddy Brook could be the capped landfill immediately upstream and adjacent to this tributary. Historic monitoring of the site has indicated moderate impairment of the macroinvertebrate community in Muddy Brook, but relatively low fecal coliform and nutrient concentrations suggest a cause other than failing septic systems. Additional samples for ammonia will be collected upstream of the landfill in 2001 to help determine if it is the source of this pollutant.

Phosphorus is an important nutrient, and has been determined to be the limiting factor controlling algal productivity in the Wachusett Reservoir. EPA Water Quality Criteria (1976) recommended a maximum concentration of 0.05 mg/L total phosphorus in tributary streams in order to prevent accelerated eutrophication of receiving waterbodies. Concentrations measured in the Wachusett tributaries ranged from below the detection limit of 0.005 mg/L to 0.468 mg/L total P during 2000. No more than two samples per tributary exceeded the recommended concentration in all but French Brook and the Quinapoxet and Stillwater Rivers. Mean total phosphorus concentrations were below 0.05 mg/L in most streams, but were higher in Cook Brook (Stoneleigh), Malden Brook, and the Quinapoxet and Stillwater.

TABLE 7

TOTAL PHOSPHORUS CONCENTRATIONS (mg/L)

station	FRENCH	MALAGASCO	MUDDY	GATES	W.BOYLSTON	MALDEN	QUINAPOXET	STILLWATER
MAX	0.098	0.073	0.025	0.075	0.037	0.272	0.192	0.468
MIN	0.010	0.012	0.008	0.014	0.007	0.014	0.010	0.019
MEAN	0.043	0.031	0.016	0.034	0.019	0.053	0.061	0.083
MED	0.042	0.030	0.016	0.029	0.018	0.028	0.033	0.040

TABLE 7 (cont.)

TOTAL PHOSPHORUS CONCENTRATIONS (mg/L)

station	COOK (Stoneleigh)	COOK (Shrewsbury)	COOK (Wyoming)	JORDAN FARM	ROCKY (East)
LANDUSE	[residential]	[residential]	[residential]	[agriculture]	[undeveloped]
MAX	0.111	0.064	0.095	0.023	0.008
MIN	0.015	0.015	0.008	0.011	<0.005
MEAN	0.052	0.029	0.027	0.015	0.006
MED	0.041	0.023	0.020	0.013	0.006

Most annual mean and median concentrations were comparable to historic measurements, although Malagasco Brook, Muddy Brook, and West Boylston Brook recorded their lowest ever annual means. Most concentrations were also similar to those measured in 1999, although Jordan Farm Brook and Cook Brook showed improvements. Samples from French Brook and the Stillwater River contained significantly more total phosphorus than the previous year, probably due to the presence of beaver during part of the year at both locations.

Total phosphorus concentrations were generally uniform throughout the period with an occasional short term increase noted (see Figures 5 and 6 on the following page). Concentrations increased during the spring and summer in French Brook, presumably the result of the arrival of beaver at that sampling site. The animals were subsequently removed and concentrations were down at the end of the year. Total phosphorus concentrations in the Quinapoxet River rose sharply at the end of the summer and remained elevated from September through November. The cause for this increase has not been determined. No other obvious seasonal pattern was noted in any of the streams.

Silica concentrations ranged from a low of 1.36 mg/L (Quinapoxet, 1/19/00) to a high of 84.1 mg/L (French, 1/18/00). Annual mean concentration in the watershed during 2000 was 9.56 mg/L, although this would drop to 9.06 mg/L if the extreme high value from French Brook was not included. Most tributaries generally tended to have lower concentrations early in the year (February/March – May/June) with higher concentrations during the winter and summer months. This is probably the result of sand applications to road surfaces (winter) and concentration of stream contaminants during low flow (summer). French and Malden Brooks had the highest annual mean concentrations, followed by the three Cook Brook stations and West Boylston Brook. The Quinapoxet and Stillwater Rivers had the lowest annual mean concentrations; Muddy Brook was only slightly higher. If annual median concentrations are examined (lessening the impact of extreme samples like the January maximum on French Brook) then the tributaries with the most silica are Cook, Malden, Gates, West Boylston, and Malagasco Brooks.

Figure 5

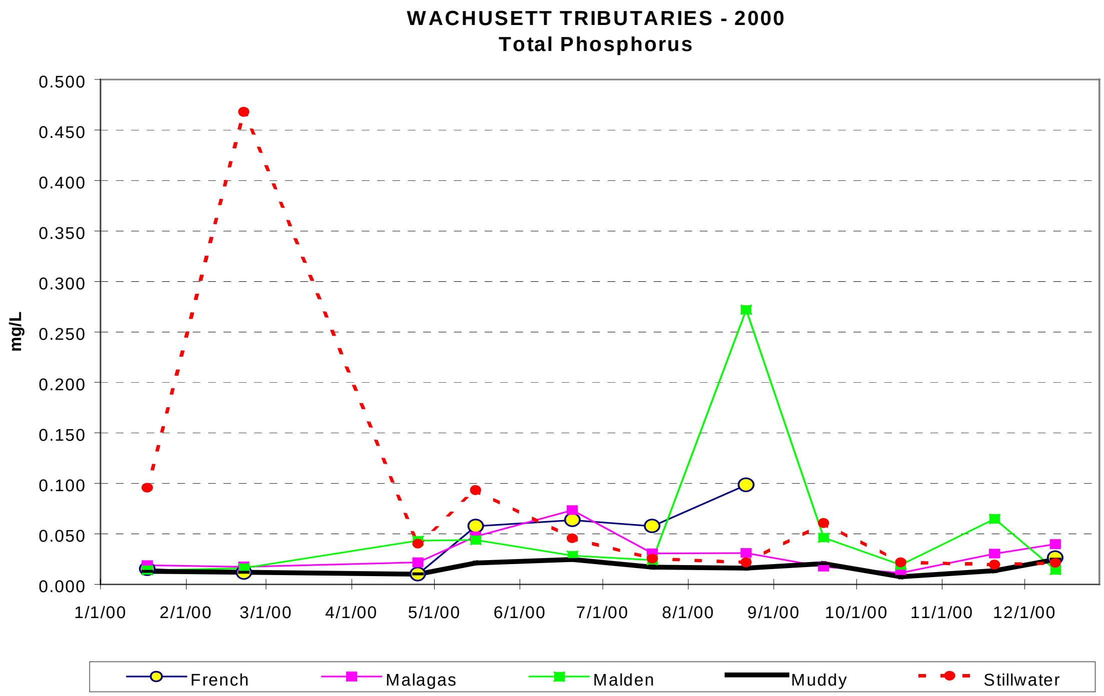
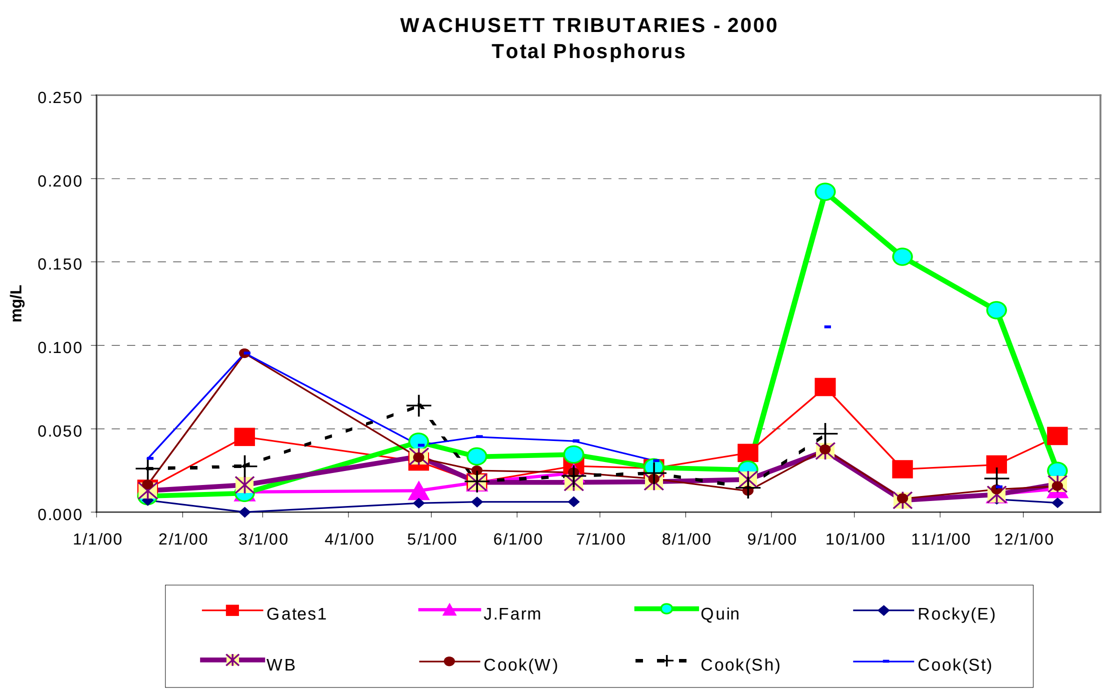


Figure 6



Total suspended solids are those particles suspended in a water sample retained by a filter of 2µm pore size. These particles can be naturally occurring or might be the result of human activities. Total suspended solids in the Wachusett tributaries ranged from <1 to 357 mg/L, with an overall mean of 8. High suspended solids were measured on more than date in Malden and Muddy Brooks and in the Quinapoxet and Stillwater Rivers. Some of the smaller tributaries (Gates, West Boylston, Cook (Wyoming), Jordan Farm, and Rocky (East Branch)) never had measurements in excess of 5 mg/L.

Total organic carbon (TOC) and UV-254 measure organic constituents in water and are important as a way to predict precursors of harmful disinfection byproducts. TOC in the tributaries ranged from 1.06 to 25.4 mg/L, with an overall mean value of 5.4 and the highest readings from Malagasco, Malden, and French Brooks. Many of the streams had stable TOC readings throughout the year, although values in French Brook increased with the prolonged presence of beaver. Elevated values were also seen in Malagasco Brook and in the Quinapoxet River in the late autumn after leaf fall. UV-254 measurements were comparable to TOC measurements as expected. Organic compounds such as tannins and humic substances absorb UV radiation and there is a correlation between UV absorption and organic carbon content. The highest UV-254 readings were from Malagasco, Malden, and French Brooks.

3.1.3 CONDUCTIVITY

Fresh water systems almost always contain small to moderate amounts of mineral salts in solution. Conductivity is a measure of the ability of water to carry an electric current, which is dependent on the concentration and availability of these ions. Elevated conductivity levels are indicative of contamination from stormwater or failing septic systems, or can be the result of watershed soil types.

In order to provide a more accurate representation of tributary water quality, criteria were proposed by the DWM during the mid 1990s which relate conductivity and fecal coliform levels to the likelihood of contamination from failing septic systems. A simple statistical analysis was used to develop a ranking system for tributaries, using percent exceedance of specific criteria. Tributaries with more than fifty percent of the samples exceeding the Class A Standard for fecal coliform of twenty colonies per 100 mL are considered impacted by septic systems. The impact is considered minor if less than eighty percent of samples exceed a conductivity standard of 120 µmhos/cm, moderate if greater than eighty percent of samples exceed the 120 µmhos/cm standard, and severe if more than twenty percent of samples exceed a standard of 360 µmhos/cm. These criteria appear to give a fairly good indication of whether or not a sampling location is impacted by failing septic systems rather than by an alternative source of contamination, although annual flow conditions need to be considered. Stream flow appears to be directly related to conductivity, with "dry" years (low flows) concentrating contaminants during the warm months and elevating mean annual conductivity. Years with less precipitation and lower tributary flow result in higher overall conductivity measurements and appear to increase the number of streams severely impacted. For this reason it is suggested that more than a single year be used in assessing these criteria.

Conductivity was measured weekly on the tributaries, with values ranging from 12.1 (Bailey Brook) to 3198 (Gates Brook – Lombard Avenue) μmhos/cm. Annual mean values ranged from 29.1 (Bailey Brook) to 655.5 (Beaman Pond Brook) μmhos/cm. Extreme high values such as the one from Gates Brook were generally recorded following winter storms and concurrent salt applications. Very high readings were once again noted from East Wachusett (31) Brook during the summer, and this time the source was positively identified as groundwater contaminated by the nearby municipal salt storage facility. Groundwater seepage entering East Wachusett Brook had a measured conductivity exceeding 5000 μmhos/cm. Except for samples impacted by storm events, conductivity values in most tributaries were generally highest in the summer and early fall when flows were lowest and lower in the winter and spring when flows were high.

An assessment of conductivity and fecal coliform data from 2000 using criteria previously described found that fifteen of forty-six stations were likely contaminated by improperly functioning septic systems. Thirteen of these stations (Beaman Pond Brook, Oakdale Brook, Houghton Brook, West Boylston Brook, Scarlett Brook, two stations on Cook Brook, and six stations on Gates Brook) were considered severely impaired. The latter four tributaries are no surprise; sewers in Holden and West Boylston are under construction specifically to deal with the problem. The subwatersheds of Beaman Pond, Oakdale, and Houghton Brooks do not have obvious problems with septic systems, however, and an effort should be made to identify and correct these faulty systems.

The criteria suggest that the station on Malagasco Brook was moderately impaired by septic systems in 2000, but appear to hint at only minor impacts from septic systems for Asnebumskit Brook at Princeton Street, even though the latter was highly contaminated throughout the spring, summer, and fall. Contamination of Asnebumskit Brook at Princeton Street has been determined to be primarily the result of pigeons roosting beneath the Route 122A bridge, so this assessment is accurate.

A quick comparison of this assessment with one done in 1998 and 1999 seems to indicate improving conditions in the watershed. A lower percentage (33%) of tributaries overall was assessed as likely contaminated by faulty septic systems, down from 38% in 1999 and 47% in 1998. Annual weather conditions and tributary flows do not appear to be the primary cause; a real improvement in water quality seems to be taking place as septic systems are repaired and new sewers are made operational.

3.1.4 TEMPERATURE

Temperatures in the tributaries ranged from just below zero to 24.9 degrees C, with subzero temperatures recorded in January, February, and March. Temperatures in all tributaries increased steadily between April and July and began to decline in early September.

3.1.5 HYDROGEN ION ACTIVITY (pH)

Hydrogen ion activity, or the measure of a solution's acidity or alkalinity, is expressed as pH on a scale ranging from 0 to 14. Underlying geologic formations, biological processes, and human contaminants impact the pH of a water body. In this region most streams and lakes tend to be relatively acidic (pH less than 7) due to granite bedrock and the impact of acid precipitation originating from the Midwest.

No measurements of pH were done during 2000. More than a decade of routine sampling in the tributaries has shown very little variation either seasonally or over time. Low values in some tributaries may have been caused by impacts of runoff from acid precipitation, while all other recorded values are considered to be representative of normal background conditions.

3.1.6 *GIARDIA / CRYPTOSPORIDIUM*

Giardia and *Cryptosporidium* samples were collected once or twice from February through December. Thirty-eight samples were collected from stations on the Quinapoxet and Stillwater Rivers, the two largest tributaries to the reservoir. Baseline information on seasonal occurrence of these pathogens was gathered and added to an expanding database. Results of this sampling program are discussed below.

The contract laboratory used for analysis has almost always been able to produce detection limits of less than one organism per 100L, with an average detection limit during 2000 of 0.41 organisms per 100L. On two occasions during the year the detection limit was higher than desired, with a maximum of 1.06 per 100L in a sample collected during a storm event. Confirmed *Giardia* cysts were collected from the Stillwater River in mid April, but even with low detection limits, no confirmed *Cryptosporidium* oocysts were found. Presumptive *Giardia* cysts were found in fifty-eight percent of the samples from the Stillwater and in forty-two percent of the samples from the Quinapoxet, similar to the percentages detected in 1999. Presumptive organisms are the correct size and shape and fluorescent color, but the internal structures observed in confirmed organisms are not visible. Five percent of the samples from the Stillwater and twenty-one percent from the Quinapoxet contained presumptive *Cryptosporidium* oocysts. This was a considerably lower percentage than the previous year. It should be noted that detection of these protozoa in a sample, whether presumptive or confirmed, does not necessarily mean that viable or infective organisms are actually present within the tributary. In addition, the presence of protozoa in watershed tributaries does not mean that any are reaching the Cosgrove Intake.

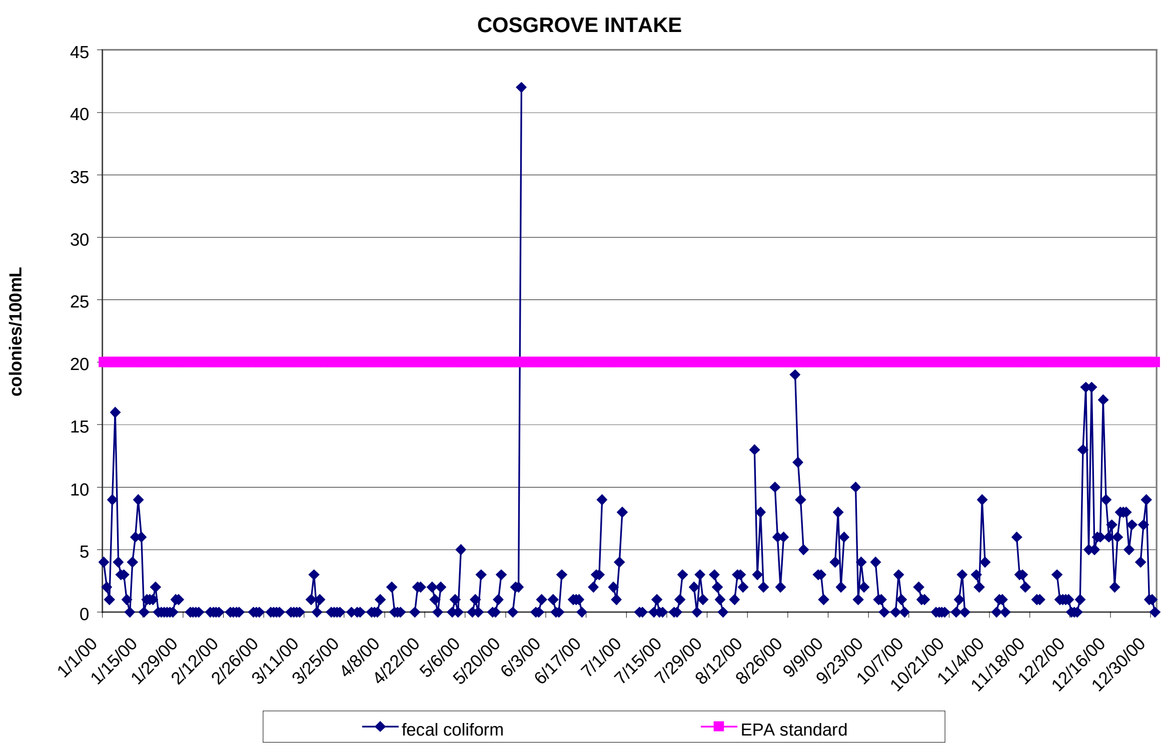
Some differences between the two tributaries were observed. The Stillwater River had a greater percentage of samples containing presumptive *Giardia* cysts (58% vs. 42%) while the Quinapoxet River had a greater percentage of samples containing presumptive *Cryptosporidium* oocysts (21% vs. 5%). There were seasonal differences noted as well, common to the two tributaries. Both *Giardia* and *Cryptosporidium* were found primarily in the late winter, spring, and fall, with no samples positive for either organism in June, July, or September. A different pattern was observed in 1999, when presumptive cysts were found from January through March in samples from the Stillwater, from the Quinapoxet in March, May, and June, and in both rivers in July through September. No clear seasonal trends have been determined, and presence or absence may be related more to precipitation, flow conditions, and presence of wildlife rather than season. Sampling of these tributaries will continue through 2001 in an attempt to improve our understanding of the presence of these protozoa.

3.2 RESERVOIR

3.2.1 BACTERIA

A total of 222 bacteria samples were collected at the Cosgrove Intake by the DWM during 2000. Most were surface samples collected from the back walkway, but a total of 33 during January, February, March, and December were taken from an internal tap when ice formation around the intake structure precluded sampling by the usual method. EPA's fecal coliform criteria for drinking water require that at least ninety percent of all source water samples contain less than 20 colonies per 100 mL. More than ninety-nine percent of the samples collected at the Cosgrove Intake during 2000 contained less than the standard (Figure 7). The standard was exceeded only once, on May 25th, and was believed to be the result of an inadvertent discharge of debris (including bird feces) from the Cosgrove roof to the reservoir during normal maintenance activities. Problems caused by roosting gulls and other waterfowl were minimized due to a rigorous harassment program. MWRA official compliance samples are always collected from the internal tap and did not exceed the standard at any time during 2000.

Figure 7



Samples were also collected at twenty-three surface stations across the reservoir to document the relationship between seasonal bacteria variations and roosting populations of gulls and geese. Sample locations were previously shown on Figure 2. Samples were collected biweekly or monthly from January 12 through December 21, although no samples were collected in February or early March due to ice cover. The data are included in Table 8 on the following page.

Samples collected in January contained slightly elevated levels of fecal coliform at mid reservoir locations. When harassment activities are successful, birds remain at these locations for only brief periods of time before being chased further to the southwest or off the reservoir. Bacteria concentrations at most other locations on the reservoir were less than 10 colonies per 100mL in January. The Wachusett Reservoir became mostly ice-covered by the end of the month, and sampling was curtailed until the end of March.

Samples collected in March, April, and May contained only small numbers of fecal coliform bacteria at most locations, with slightly elevated levels at the southern end of the reservoir where birds continued to roost. Monthly samples from June through October contained very low levels of fecal coliform at most stations, with the exception of a single sample near the south roost area in July, a sample from Prescott Cove in September, and another sample from the south roost at the end of October. Flocks of Canada geese and migrating ducks were occasionally noticed in these locations.

Samples collected in November contained elevated levels of fecal coliform at locations throughout the southern end of the reservoir as roosting gulls returned to seasonal concentrations. Samples collected at the middle of the reservoir and near the Cosgrove Intake still contained very few fecal coliform bacteria. By December elevated levels of fecal coliform were noted throughout the middle of the reservoir both north and south of the narrows and at the southern end of the reservoir. Large numbers of migrating birds were present at this time, and most or all of the smaller water bodies in the area were covered with ice. The harassment program was intensified at this point and birds were chased from the north end of the reservoir from dawn to dark seven days per week. Bacteria concentrations did not exceed 100 colonies/100mL in any sample collected from the reservoir in 2000 other than in four samples from the southern roost area in December. Samples collected at and near the Cosgrove Intake had fewer than 20 colonies per 100 mL throughout the entire year.

The focused and concentrated bird harassment program was quite successful during 2000, with markedly fewer gulls, geese, and ducks visiting the north end of the reservoir and significantly lower fecal coliform concentrations in all samples collected. Problems with weather, prevailing wind conditions, and partial ice cover were addressed as necessary and never had a significant impact on harassment activities. A detailed summary of the harassment program with associated data is published weekly throughout the harassment season as part of the MWRA Weekly Water Quality Report.

TABLE 8
2000 FECAL COLIFORM TRANSECT DATA
WACHUSETT RESERVOIR

STATION	1/12/00	3/27/00	4/20/00	5/11/00	6/15/00	7/13/00	8/21/00	9/14/00
Cosgrove	6	0	1	3	0	0	10	6
B-2	11	0	4	0	1	0	2	10
B-3	5	0	3	4	0	0	2	2
C-1	4	0	1	1	0	0	0	4
C-3	5	0	2	2	0	0	1	2
C-5	3	0	0	25	7	0	12	3
D-1	8	0	1	0	0	0	5	2
D-2	15	1	0	6	2	0	10	2
D-4	5	0	0	5	0	0	4	1
E-2	13	0	1	2	0	1	5	0
E-4	14	0	0	6	0	0	4	0
F-2	6	0	1	3	0	2	0	2
F-3	6	0	0	1	3	0	4	35
F-4	6	0	0	3	1	0	1	1
G-2	0	0	1	2	0	0	0	1
H-2	2	0	0	0	1	0	0	2
I-2	4	2	4	2	1	0	0	0
J-2	0	0	1	6	0	0	0	0
J-3	5	2	6	5	0	0	6	1
J-4	9	29	20	7	0	0	3	1
K-2	6	0	1	9	1	57	1	2
M-1	0	0	0	58	2	0	0	3
N-1	4	2	3	5	1	0	0	3

STATION	10/5/00	10/23/00	11/16/00	12/15/00	12/21/00
Cosgrove	0	0	2	6	8
B-2	0	0	1	15	11
B-3	1	1	0	11	7
C-1	1	1	1	8	8
C-3	1	0	0	14	6
C-5	1	0	2	11	1
D-1	0	0	0	7	21
D-2	1	0	2	13	16
D-4	3	0	1	4	4
E-2	2	0	0	55	40
E-4	0	0	0	14	17
F-2	2	0	2	6	16
F-3	1	1	2	47	12
F-4	0	0	2	45	21
G-2	1	0	0	11	20
H-2	4	1	2	15	10
I-2	4	0	4	76	61
J-2	0	0	2	28	13
J-3	1	31	15	170	73
J-4	0	7	33	188	149
K-2	3	3	28	56	75
M-1	0	1	47	19	32
N-1	0	0	11	60	109

3.2.2 WATER COLUMN CHARACTERISTICS

MDC staff routinely measure water column profiles in the Wachusett Reservoir for the following parameters: temperature, dissolved oxygen, percent oxygen saturation, specific conductance, and hydrogen ion activity (pH). Profiles are measured monthly at the three main stations (Basin North/Station 3417, Basin South/Station 3412, and Thomas Basin; see Figure 1) weather and ice conditions permitting.

The frequency of profile measurement is increased to semimonthly or weekly during the summer period of thermal stratification in order to monitor growth conditions for phytoplankton and to track the progress of the Quabbin "interflow" through the Wachusett basin during periods of water transfer (see below). The thermally stratified water column of summer is characterized by a layer of warm, less dense water occupying the top of the water column ("epilimnion"), a stratum with a thermal gradient in the middle ("metalimnion"), and a stratum of cold, dense water at the bottom ("hypolimnion"). Also during the stratification period, profiles are measured at additional locations of interest including the Route 12 Bridge, the Quinapoxet Basin railroad bridge, the Beaman Street Bridge, and the Stillwater Basin railroad bridge. Profiles are measured at one meter intervals, except during periods of isothermy and mixing (generally November through March) when intervals of two or three meters are adequate to characterize the water column.

Water column profiles are measured with a "Reporter" or "H20" multiprobe and "Surveyor 3" water quality logging system manufactured by Hydrolab Corporation (Austin, Texas). This instrument is generally charged and calibrated on the day proceeding each field effort and also given a post-measurement calibration check. At the conclusion of field work, data recorded by the logging system is downloaded to a PC and transformed into an Excel spreadsheet.

Station 3417 (Basin North) has been selected for graphically depicting seasonal changes in the water column profile of Wachusett Reservoir because it is representative of the deepest portion of the basin and it is not influenced by turbulence from local water inputs or withdrawals that could disrupt profile characteristics. Profiles measured in Thomas Basin and at Cosgrove Intake (Station 3409) are influenced by inflow from the Quabbin Aqueduct and withdrawal at the Cosgrove Intake respectively.

<u>The Quabbin "Interflow" in Wachusett Reservoir</u>

The transfer of water from Quabbin to Wachusett Reservoir via the Quabbin Aqueduct has a profound influence on the water budget, profile characteristics, and hydrodynamics of the Wachusett Reservoir. During the years 1995 through 1999, the amount of water transferred annually from Quabbin to Wachusett ranged from a volume equivalent to 44 percent of the Wachusett basin up to 90 percent. The period of peak transfer rates generally occurs from June through November. However, at any time of the year, approximately half of the water in the Wachusett basin is derived from Quabbin Reservoir.

The peak transfer period overlaps the period of thermal stratification in Wachusett and Quabbin Reservoirs. Water entering the Quabbin Aqueduct at Shaft 12 is withdrawn from depths of 13 to 23 meters in Quabbin Reservoir. These depths are within the hypolimnion of Quabbin Reservoir where water temperatures range from only 9 to 13 degrees C in the period June through October. This deep withdrawal from Quabbin is colder and denser relative to epilimnetic waters in Wachusett Reservoir. However, due to a slight gain in heat from mixing as it passes through Quinapoxet Basin and Thomas Basin, the transfer water is not as cold and dense as the hypolimnion of Wachusett. Therefore, Quabbin water transferred during the period of thermal stratification flows conformably into the metalimnion of Wachusett where water temperatures and densities coincide.

The term interflow describes this metalimnetic flow path for the Quabbin transfer that generally forms between depths of 7 to 15 meters in the Wachusett water column. The interflow penetrates through the main basin of Wachusett Reservoir (from the Route 12 Bridge to Cosgrove Intake) in about 3 to 4 weeks depending on the timing and intensity of transfer from Quabbin. The interflow essentially connects Quabbin inflow to Cosgrove Intake in a “short circuit” undergoing minimal mixing with ambient Wachusett Reservoir water.

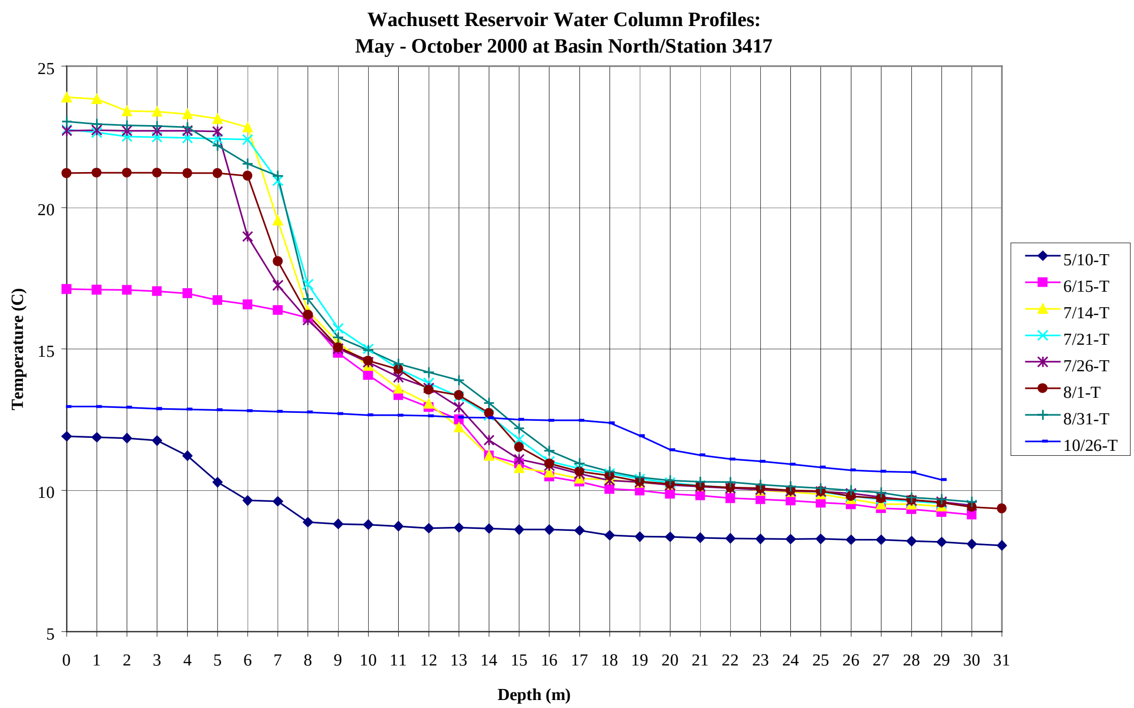
In 2000, the transfer of water from Quabbin Reservoir was initiated on June 28th. The transfer was interrupted on July 9th during the interval when the interflow was penetrating the basin due to electrical problems at Shaft 1. On July 19th, a weak conductivity minima was detected in front of Cosgrove Intake (see Section 3.2.2.3 below). Thus, in 2000, interflow transit of the basin took approximately 22 days despite detection of a weak conductivity minima at Station 3417 as early as July 12th, only 14 days after the transfer was initiated. Cessation of transfer due to problems at Shaft 1 caused the interflow to lose momentum thereby slowing penetration. The influence of the 2000 Quabbin interflow on profile characteristics in Wachusett Reservoir is discussed in the sections that follow.

3.2.2.1 TEMPERATURE

Typical of most deep lakes and reservoirs in the temperate region, the Wachusett Reservoir becomes thermally stratified in summer. Development of thermal stratification due to solar radiation and atmospheric warming in spring and summer and the subsequent loss of heat leading to fall turnover at Station 3417 (Basin North) is depicted in Figure 8.

The initial stages of thermal stratification were evident on the May 10th measurement date when a difference of approximately 4 degrees C existed between the top and bottom of the water column (Figure 8). The top of the water column continued to gain heat and the upper six meters had reached a temperature of approximately 17 degrees C by June 15th. Differences in water density resulting from the thermal gradient caused the typical stratification pattern of epilimnion, metalimnion, and hypolimnion to form in the water column.

Figure 8



The initial penetration of the interflow from Quabbin (see Interflow section above) can been seen in the profile measured on July 14th. A very steep thermal gradient exists between depths of six and eight meters in which the temperature dropped approximately seven degrees C. Profiles measured in July and August show a thermocline (defined as a temperature gradient of 1 degree C per meter or greater) beginning at a depth of 6 meters and falling steeply to temperatures characteristic of the Quabbin interflow (Figure 8). This steep gradient in temperature and density caused by the interflow stabilized the position of the metalimnion between approximately 6 and 15 meters depth.

The presence of the Quabbin interflow was also evident in the temperature profiles as a minor bump or plateau in the thermocline between 10 and 13 meters where the temperature centers around 14 degrees C (Figure 8). This plateau represents the "core" of the interflow stratum that undergoes minimal mixing with ambient Wachusett water.

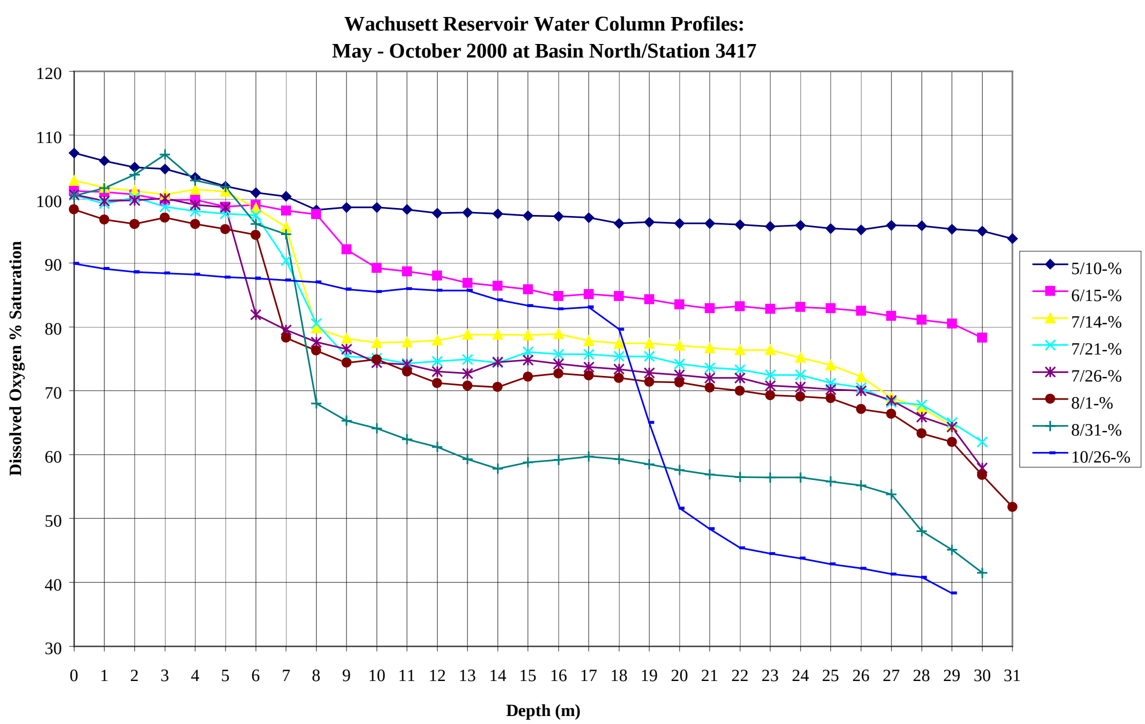
Highest temperatures in the epilimnion were recorded on July 14th at about 24 degrees C while temperatures in the hypolimnion remained at about 10 degrees C throughout the summer (Figure 8). This thermal gradient persisted through the end of August. In September, the system began to lose heat as air temperatures cooled.

Profiles measured on October 26th show that wind energy and heat losses had caused the water column to be mixed down to a depth of 18 meters thus homogenizing the epilimnion and the metalimnetic Quabbin interflow. A difference of less than 3 degrees C existed between the top and bottom of the water column at this time (Figure 8). Soon after the October 26th measurement date, wind energy dispersed the remnant stratification pattern and mixed the entire water column, in an event known as fall "turnover".

3.2.2.2 DISSOLVED OXYGEN

Measurement of dissolved oxygen profiles throughout most of the year generally show values ranging from 70 to 100 percent saturation for ambient water temperatures. However, during the period of thermal stratification, demand for oxygen in the hypolimnion reduced oxygen concentrations to as low as 37 percent saturation before fall turnover in late October or early November replenished oxygen throughout the water column. Reductions in oxygen concentration are also evident in the metalimnion during the stratification period, but these are mainly indicative of oxygen demand within the Quabbin interflow and the Quabbin Reservoir rather than processes within Wachusett Reservoir. The progressive lowering of dissolved oxygen saturation values in the metalimnion and hypolimnion from May through October at Station 3417 (Basin North) is depicted in Figure 9.

Figure 9



On July 21st, hypolimnetic dissolved oxygen concentrations range around 75 percent saturation except for the very bottom of the water column which was at 62 percent saturation. By August 31st, hypolimnetic concentrations at most depths had declined into the 55 to 60 percent saturation range with concentrations less than 50 percent recorded near the bottom of the water column (Figure 9). Relatively low saturation values measured near the bottom of the water column indicate slightly higher rates of oxygen demand by microbial decomposition processes occurring at the sediment-water interface.

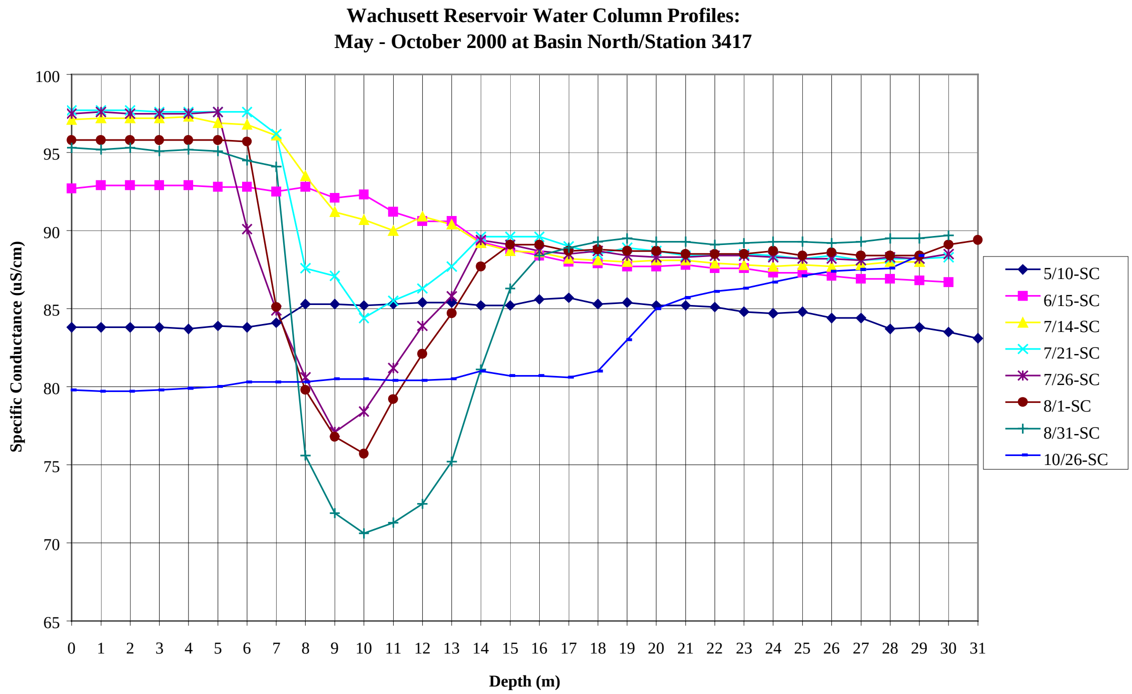
Hypolimnetic oxygen concentrations in September and October continued to decline gradually into the 50 and 40 percent saturation range. However, absolute dissolved oxygen concentrations remain above 4 ppm at all depths throughout the stratification period. Profiles measured on October 26th show that wind energy and heat losses had caused the water column to be mixed down to a depth of 18 meters with a concomitant replenishment of oxygen to greater than 80 percent saturation throughout the mixed volume. Soon after the October 26th measurement date, wind energy dispersed the remnant stratification pattern mixing and exposing the entire basin volume to the atmosphere thereby replenishing dissolved oxygen concentrations at all depths.

3.2.2.3 CONDUCTIVITY

Specific conductance ("conductivity") profiles in Wachusett Reservoir reflect the interplay between native water contributed from the Wachusett watershed and water transferred from Quabbin. The Quinapoxet and Stillwater Rivers are the two main tributaries to Wachusett Reservoir and are estimated to account for approximately 75 percent of annual inflow from the reservoir watershed. Measurements of conductivity in these rivers generally range between 60 and 240 µmhos/cm with an average value between 125 and 150 µmhos/cm. In contrast, the average conductivity value of Quabbin water is approximately 40 µmhos/cm. Typically, during periods of isothermy and mixing (November through March), conductivity values throughout the main Wachusett basin range from 75 to 100 µmhos/cm depending on the amount of water received from Quabbin. During the summer stratification period the Quabbin interflow is conspicuous in profile measurements as a metalimnetic strata of low conductivity. Figure 10 depicts conductivity profiles measured at Station 3417 (Basin North) from May through October.

On June 15th, before the Quabbin transfer had been initiated, conductivity values ranged between 87 and 93 µmhos/cm throughout the water column. The profiles recorded from July 14th through August 31st show the development of the interflow stratum as a "trough" in the conductivity profile between depths of 7 and 15 meters (Figure 10). This trough intensifies (extends to lower conductivity values) over the period of transfer as water in the interior of the interflow undergoes less mixing with ambient reservoir water at the boundaries of the interflow stratum. On August 31st, a minimum interflow conductivity value of 71 µmhos/cm was observed at a depth of 10 meters at Station 3417.

Figure 10



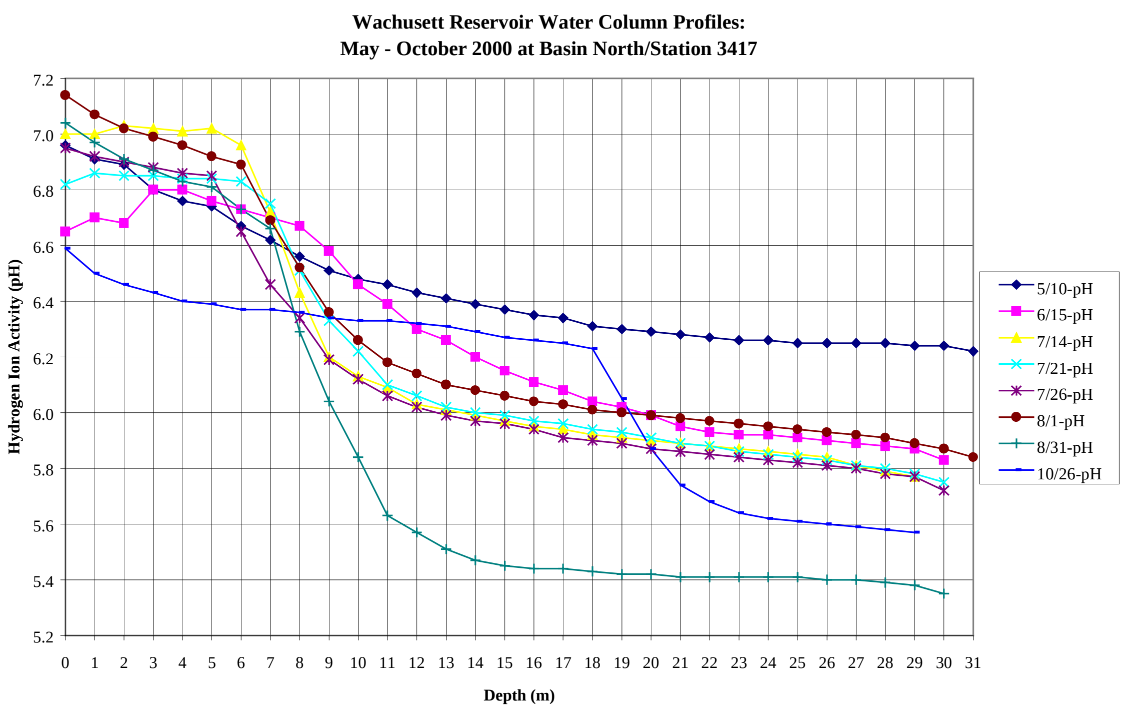
Profiles measured on October 26th show that wind energy and heat losses had caused the water column to be mixed down to a depth of 18 meters. The conductivity of the stratum resulting from the homogenization of the epilimnion and metalimnetic Quabbin interflow was approximately 80 µmhos/cm. A slight gradient of increasing conductivity persisted below 18 meters (Figure 10). Soon after the October 26th measurement date, wind energy dispersed the remnant stratification pattern and mixed the entire water column with a resulting conductivity value of approximately 76 µmhos/cm measured uniformly throughout.

3.2.2.4 HYDROGEN ION ACTIVITY (pH)

Hydrogen ion activity (pH) in Wachusett Reservoir is determined ultimately by the exchange of inorganic carbon between the atmosphere and water (the carbon dioxide-bicarbonate-carbonate "buffering system"). The opposing processes of photosynthesis and respiration determine specific patterns of pH distribution vertically in the water column and seasonally over the year. Generally, pH values in Wachusett Reservoir range from around neutral (pH=7) to slightly acidic (pH=6). Figure 11 depicts pH profiles measured at Station 3417 (Basin North) from May through October.

Photosynthesis by phytoplankton results in the uptake of carbon dioxide dissolved in the water. The uptake of carbon dioxide tends to increase pH in the epilimnion where photosynthetic activity is greatest. Maximum pH values of around 7.1 were observed in the epilimnion. Photosynthetic activity maintained epilimnetic pH around a value of 6.9 through August. Values of pH ranging from 6.0 to 6.6 were measured in the metalimnion during the stratification period, but these are mainly indicative of the Quabbin interflow and the Quabbin Reservoir rather than processes within Wachusett Reservoir.

Figure 11



In contrast to the utilization of carbon dioxide by photosynthetic organisms, microbial decomposition of organic matter produces carbon dioxide. In the hypolimnion, where microbial respiration is the dominant process, the production of carbon dioxide tends to decrease pH. In June, soon after the establishment of thermal stratification, pH values in the hypolimnion had decreased to around 6.0. Hypolimnetic pH values continued to decrease to a minimum of 5.4 by the end of August. Wind energy dispersed the stratification pattern at turnover with resulting pH values of between 6.0 and 6.5 measured uniformly throughout the mixed water column.

3.2.2.5 TURBIDITY

The Division no longer measures turbidity values at the Cosgrove Intake weekly since the MWRA records this information continuously. Turbidity values were low throughout the year, well below the EPA's filtration avoidance criteria of 5 NTU.

3.2.3 NUTRIENTS

Sampling for measurement of nutrient concentrations in Wachusett Reservoir has been conducted quarterly since the conclusion of the program of monthly sampling conducted from October 1998 to September 1999. Quarterly sampling was conducted at the onset of thermal stratification (May), in the middle of the stratification period (late July/early August), near the end of the stratification period (October), and during a winter period of mixis (isothermal mixing) before the development of ice cover (December). Samples were collected at three of the main stations used in the 1998-99 year of study (Basin North/Station 3417, Basin South/Station 3412, and Thomas Basin; see Figure 1).

Samples were collected in the epilimnion, metalimnion, and hypolimnion during the period of thermal stratification and near the top, middle, and bottom of the water column during mixis. Water column profiles of temperature, dissolved oxygen, and other parameters measured with a multiprobe were evaluated in the field to determine depths for metalimnetic samples.

Quarterly sampling continued to be performed in collaboration with MWRA staff at the Deer Island Central Laboratory who provided sample containers and where all grab samples were sent for analysis. Sampling protocol, chain-of-custody documentation, and sample delivery were similar to those established in the 1998-99 year of study. Details of sampling protocol are provided in Table 9. Modifications to the quarterly sampling program consisted only of a lower minimum detection limit for total Kjeldahl-nitrogen (reduced to 0.2 mg/L from 0.6 mg/L) and the addition of UV254 among the parameters to be measured. Analysis of the new data resulting from these modifications will be conducted in the future when a larger database has been generated.

Table 9 - Wachusett Reservoir Nutrient Analyses

Parameter and Method	Preservation	Holding Time	Detection Limit
Total Phosphorus EPA – 365.1	Frozen	indefinite	5 µg/L
Ammonia-Nitrogen EPA – 350	Filtered and Frozen	indefinite	5 µg/L
Nitrate-Nitrogen EPA - 353.2	Filtered and Frozen	indefinite	5 µg/L
Total Kjeldahl-Nitrogen EPA - 351.2	Sulfuric Acid	28 days	200 µg/L
Silica EPA - 200.7	Nitric Acid	28 days	10 µg/L
Alkalinity EPA - 310.1	Refrigeration	14 days	10 µg/L as $CaCO_3$
UV-254	Refrigeration	28 days	not applicable

The nutrient database for Wachusett Reservoir established in the 1998-99 year of monthly sampling is used as a basis for interpreting data generated more recently in quarterly sampling efforts. Results of quarterly nutrient sampling in 2000 (and from December 1999) document concentrations that generally register within or close to the ranges observed in the 1998-99 year of monthly sampling (Table 10; see complete quarterly database in Appendix). However, a few of the values of ammonia, nitrate, silica, and total phosphorus measured in 2000 were notable in registering higher than the ranges observed in the 1998-99 database. Almost all these higher values were measured in the May 2000 samples. The occurrence of these higher values in May is significant for identifying a probable explanation.

Table 10 - Wachusett Reservoir Nutrient Concentrations

Comparison of Ranges from 1998-99 Database of Monthly Sampling to Quarterly Sampling Conducted Through December 2000 (1)

Sampling Station (2)	Ammonia (NH3; µg/L)		Nitrate (NO3; µg/L)		Silica (SIO2; mg/L)	
	1998-99	Quarterly	1998-99	Quarterly	1998-99	Quarterly
Basin North/3417 (E)	<5 - 10	<5 - 12	<5 - 92	31 - 113	1.29 - 2.45	1.15 - 2.64
Basin North/3417 (M)	<5 - 13	9 - 28	<5 - 93	49 - 134	1.41 - 2.54	1.84 - 3.13
Basin North/3417 (H)	<5 - 34	10 - 19	73 - 187	49 - 156	2.14 - 3.92	1.84 - 3.55
Basin South/3412 (E)	<5 - 9	7 - 14	<5 - 107	37 - 123	1.34 - 2.79	1.18 - 2.91
Basin South/3412 (M)	<5 - 10	8 - 26	11 - 100	49 - 124	1.40 - 2.64	1.91 - 2.87
Basin South/3412 (H)	<5 - 36	8 - 22	74 - 173	49 - 141	2.23 - 3.74	1.94 - 3.43
Thomas Basin (E)	<5 - 15	<5 - 18	<5 - 177	38 - 146	1.43 - 5.00	1.26 - 3.58
Thomas Basin (M) (4)	<5	6 - 18	<5 - 11	39 - 168	1.29 - 1.52	1.34 - 3.73
Thomas Basin (H)	<5 - 11	6 - 21	<5 - 170	38 - 176	1.26 - 4.76	2.07 - 4.11

Sampling Station (2)	Total Phosphorus (µg/L)		Alkalinity (mg/L as CaCO3)	
	1998-99	Quarterly	1998-99	Quarterly
Basin North/3417 (E)	<5 - 10	6 - 13	4.60 - 6.17	4.66 - 5.80
Basin North/3417 (M)	<5 - 10	6 - 11	3.86 - 5.47	4.68 - 5.70
Basin North/3417 (H)	<5 - 12	6 - 10	4.50 - 8.67	4.80 - 5.56
Basin South/3412 (E)	<5 - 11	<5 - 12	4.42 - 10.20	4.70 - 5.68
Basin South/3412 (M)	<5 - 10	7 - 11	4.16 - 5.13	4.76 - 5.36
Basin South/3412 (H)	<5 - 10	6 - 10 (3)	4.62 - 5.64	4.68 - 5.60
Thomas Basin (E)	<5 - 18	6 - 20	3.22 - 6.57	3.52 - 7.34
Thomas Basin (M) (4)	<5 - 9	7 - 15	3.73 - 8.36	3.54 - 6.58
Thomas Basin (H)	<5 - 22	7 - 13	1.59 - 6.94	3.82 - 7.62

(1) Quarterly sampling conducted December 1999, May 2000, August 2000, October 2000, and December 2000
(2) Water column locations are as follow: E = epilimnion/surface, M = metalimnion/middle, H = hypolimnion/bottom
(3) Anomalous total phosphorus concentration of 237 µg/L omitted
(4) The 1998-99 database for the middle of the water column in Thomas Basin consists of only four sampling dates all during the Quabbin transfer period

Nutrient concentrations in Wachusett Reservoir are influenced by a variety of factors that fluctuate annually including amounts of runoff discharged from the watershed (rain and snowmelt), nutrient loading rates associated with the runoff, and populations dynamics of phytoplankton. Overriding these factors however, is the timing and duration of the Quabbin transfer. Water quality within the reservoir basin reflects a dynamic interaction between the influence of the Wachusett watershed and the influence of the Quabbin transfer. The Quabbin transfer is characterized by water of very low nutrient concentrations whereas the influence of the Wachusett watershed is exerted mostly via discharges of the Quinapoxet and Stillwater Rivers with higher nutrient concentrations.

The interplay between these two influences results in slight shifts in the range of nutrient concentrations from one year to the next. Historically, the peak period of transfer from Quabbin consists of July, August, and September each year, but it has been initiated as early as May and has extended through December or even into the initial months of the next year. In a year with early initiation of the Quabbin transfer, such as 1999 when the transfer started on May 3rd, nutrient concentrations will range lower due to the greater proportion of Quabbin derived water occupying the basin. At the conclusion of 1999, the transfer volume totaled 225 million cubic meters, equivalent to 90 percent of the Wachusett basin volume.

Conversely, in a year such as 2000 when the transfer was not initiated until June 28th, nutrient concentrations will range higher as discharges from the Quinapoxet and Stillwater Rivers have greater proportional influence. At the conclusion of 2000, the transfer volume totaled 179 million cubic meters, equivalent to 71 percent of the Wachusett basin volume. The relatively elevated concentrations observed in May 2000 reflect a stronger watershed influence because of the late entry and diminished proportion of Quabbin water in the basin compared to 1999.

Other than the slight expansion in the ranges of nutrient concentrations in 2000 discussed above, the seasonal and vertical patterns in the distribution of nutrients from quarterly samples were comparable to those documented in the 1998-99 database. These patterns are detailed in the Water Quality Report: 1999 - Wachusett Reservoir and Watershed (MDC, 2000). Future nutrient sampling at Wachusett Reservoir is planned to continue on the quarterly schedule.

3.2.4 ALGAE

Algae samples were collected once or twice weekly off the back of the Cosgrove Intake from January 3 through December 18, except for eight weeks during January and February when the reservoir was ice covered. Grab samples were taken from 0m, 6m, 8m, 10m, 12m, and 14m using a 2 liter Van Dorn bottle.

A total of 281 discrete samples were collected and analyzed. Half liter samples were concentrated to twelve mL by gravity filtration through sand and silk in Sedgewick-Rafter (SR) funnels. A one mL subsample was placed in a SR counting cell, allowed to settle for fifteen minutes, and then examined at 100X magnification. Algae were identified and counted in three strips comprising approximately ten percent of the subsample. The underside of the coverslip was also scanned to observe any floating bluegreen algae (*Anabaena*) or mobile golden-browns (*Synura*, *Uroglena*, *Dinobryon*).

Only golden-brown genera were identified and counted in samples collected from 6m, 10m, and 12m depths and from the second weekly samples. Detection of golden-brown genera was enhanced by using a 7 - 45X stereozoom dissecting microscope to scan the entire cell prior to examination at 100X.

Data collected are located in an appendix to this report. They are also accessible as part of an electronic database (Microsoft Excel file ALGAE00.XLS) and on paper at the MDC-DWM Water Quality Lab in West Boylston, Massachusetts.

Taxonomic composition, density, and seasonal dynamics of the plankton community throughout Wachusett Reservoir were evaluated through an additional program of quarterly sampling at three sampling stations within the basin (identified in Section 2.0). Transparent vinyl tubing (1 inch O.D. x 3/4 inch I.D.) was used to collect depth-integrated samples. The weighted end of the tube was lowered from the surface to a pre-selected depth, the surface end of the tube stoppered to prevent loss of water during tube retrieval, and the tube retrieved with an extracted "core" of the water column. The water in the tube was transferred into a polyethylene bottle (4 liter capacity measuring approximately 30 cm high and 15 cm in diameter) rendering a composite sample of plankton over that depth.

Integrated samples were generally collected to a depth of 15 meters, which was approximately the depth to the bottom of the metalimnion (and "interflow" stratum; see Section 3.2.2 above) during the period of thermal stratification. Data from water column profiles of dissolved oxygen and hydrogen ion activity (pH) indicate that most photosynthetic activity occurs in the epilimnion and metalimnion which were represented in their entirety in the samples integrated to 15 meters. This sampling depth was maintained during non-stratified conditions to provide consistency in the data.

Samples were preserved in the field with Lugol's Solution (3 ml per 1,000 ml of sample according to <u>Standard</u> <u>Methods</u>) and transported to the lab for processing. Prior to microscopic analysis, all samples were concentrated by a process of sedimentation. This entailed keeping the sample bottles undisturbed for a least one week to allow the organisms to settle to the bottom and then decanting the overlying supernatant in each bottle with a peristaltic pump. The one week minimum sedimentation period surpasses the EPA (1973) guideline of 4 hours per 1 cm depth of sample bottle. Samples were concentrated generally between 5% and 15% of their original volume by this process. Final results reported for each sample will incorporate the appropriate correction factor.

In addition to the quantitative samples of plankton collected with the integrated tube sampler, a net was used to collect qualitative samples of the larger forms of plankton. A plankton net of 35 micron mesh was manipulated vertically in the water column at Station 3417 (Basin North) in conjunction with monthly collection of integrated tube samples. The net filters and concentrates plankton from an unknown quantity of water and cannot provide estimates of density, but does enable the relative abundances of the larger forms to be determined.

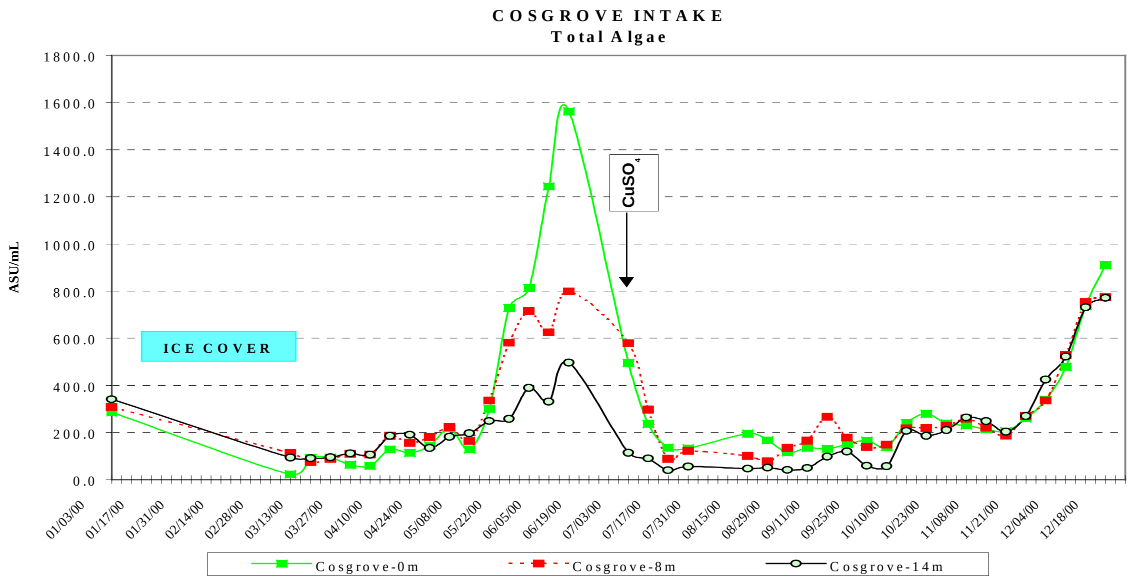
Microscopic analysis of plankton samples was performed with a compound microscope capable of magnification from 40 to 1,000 times and using phase-contrast illumination. Plankton taxa in the integrated samples were enumerated using a Sedgewick-Rafter (S-R) Cell which enables plankton densities to be quantified. Each concentrated sample was inverted a few times to homogenize the sample and then 1 ml of the sample was withdrawn with a pipette and placed into the S-R Cell. Approximately 15 minutes were allowed for the plankton to settle to the bottom of the S-R Cell before enumeration. Plankton were enumerated in a total of 10 fields described by an ocular micrometer. At 200X magnification, the ocular field measures 0.3136 square millimeters in area (previously calibrated with a stage micrometer) and the fields were selected for viewing at approximately 0.5 cm intervals across the length of the S-R Cell.

Plankton densities were expressed as Areal Standard Units (ASUs; equivalent to 400 square microns). The area of each specimen viewed in each counting field was estimated using the ocular micrometer (the ocular field was divided into a 10 by 10 grid, each square in the grid having an area of 3,136 square microns or 7.84 ASUs at 200X magnification). In the case of taxa which form gelatinous envelopes or sheaths, such as *Microcystis*, the area of the envelope was included in the estimate for that specimen. The areal extent of certain colonial taxa, such as the diatoms *Asterionella* and *Tabellaria*, was estimated by measuring the dimensions of one cell and multiplying by the number of cells in the colony. Cell fragments or structures lacking protoplasm, including lorica of *Dinobryon*, diatom frustules, and thecae of dinoflagellates were not counted.

Phytoplankton and zooplankton were generally identified to genus, although copepods were identified only to suborder (Calanoida or Cyclopoida) at the present time. An effort was made to identify dominant forms of plankton to species. Taxonomic references used to identify plankton are listed at the end of this report. Analysis of preserved plankton samples collected quarterly is still in progress and will be reported in a later publication.

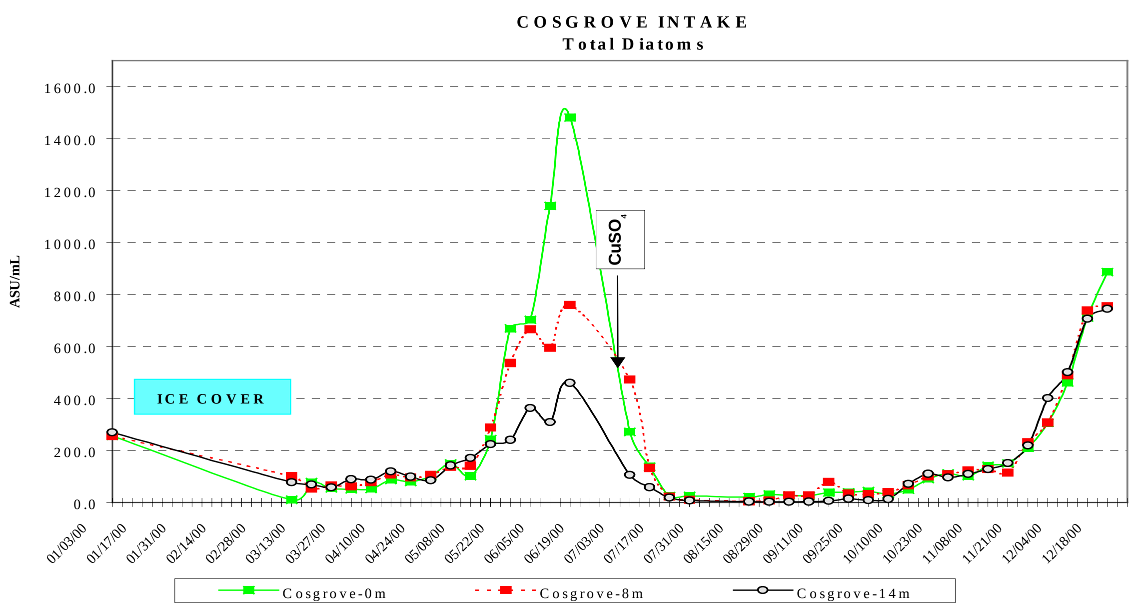
Algal populations at the Cosgrove Intake in 2000 again followed one of the two basic annual patterns seen during a majority of the last twelve years, beginning with low total concentrations in January (Figure 15). Concentrations declined slightly under the ice and then rebounded slowly throughout the spring, returning to pre-ice concentrations by the middle of May. Total concentrations then increased rapidly from mid May to mid June, reaching an annual high of nearly 1600 ASU/mL at the surface and between 500 and 800 ASU/mL at other depths. Numbers at all depths declined sharply, both prior to and following an application of copper sulfate on July 7th by the MWRA and were less than 200 ASU/mL by mid July. Total algae concentrations fluctuated between 100 and 300 ASU/mL from mid July through the middle of November and then increased rapidly once again at the end of the year (Figure 12).

Figure 12



Late winter and spring populations were comprised primarily (45-95%) of diatoms. *Asterionella* was the dominant genus (15-87%) through the middle of June at the surface, but populations then began to decline due to increasing water temperatures and depletion of necessary nutrients such as silica. This genus remained dominant at depth until the July copper sulfate treatment. *Rhizosolenia* concentrations began to increase in April but never made up more than 28-39% of the total algal population. A similar percent composition was noted in 1999, unlike the spring of 1998 when half of all algae collected at the beginning of May were *Rhizosolenia* (Figure 13).

Figure 13



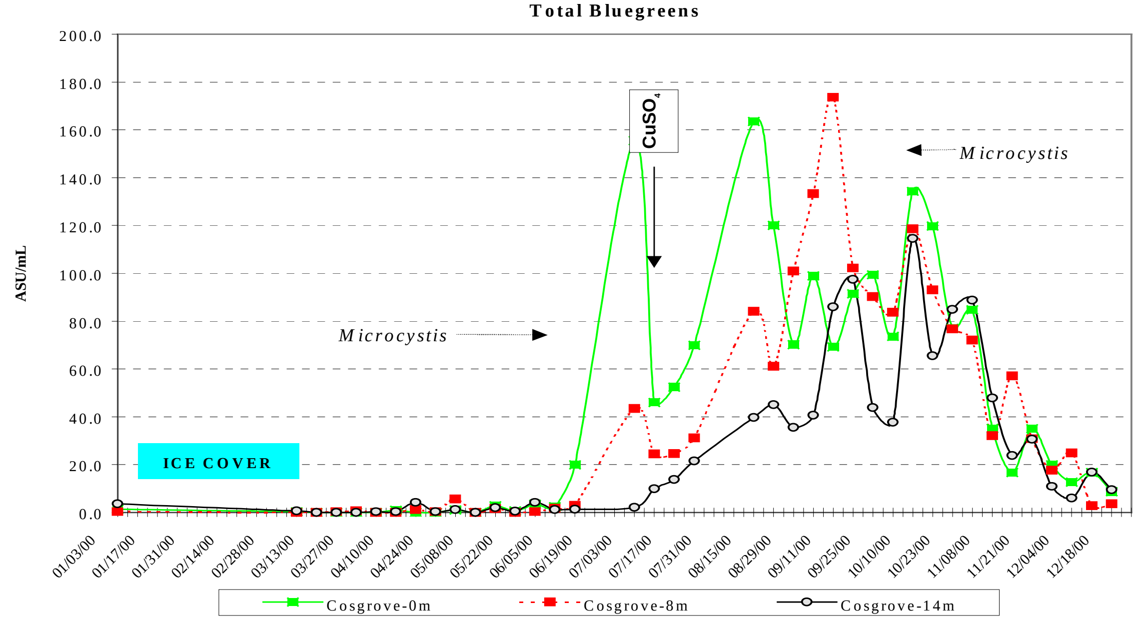
Total diatom concentrations had declined at all depths by the beginning of August and remained less than 100 ASU/mL until mid October, when numbers began to increase. Diatom concentrations increased steadily until mid November and then rose sharply, with concentrations of 750 – 900 ASU/mL by the end of the year (Figure 13).

Bluegreen algae were present at very low concentrations from January through June, with total numbers never exceeding 20 ASU/mL. Numbers increased sharply in late June with a bloom comprised primarily of the colonial alga *Microcystis*. Samples collected from the surface contained concentrations of total bluegreens in excess of 150 ASU/mL, while samples from depth had significantly lower concentrations. Elevated levels of diatoms and golden-browns were also present at this time and the northern end of the reservoir was immediately treated with copper sulfate to keep concentrations from increasing further and to avoid the development of taste and odor problems. It appears that the early treatment may have suppressed the annual bloom of *Anabaena*, because only very low concentrations of this problematic genus were noted during 2000.

Total bluegreens were present at greater than normal levels throughout the summer, with concentrations at the surface declining to just below 50 ASU/mL following treatment and then fluctuating between 70 and 163 ASU/mL for the remainder of the summer and fall. *Microcystis* continued to make up a significant proportion of the bluegreen population. Concentrations were somewhat lower at depth, but significant amounts of bluegreens were present at all depths throughout the summer and fall, and in fact reached a maximum concentration of 173 ASU/mL at 8m in September. Bluegreen algae concentrations at all depths began to decline in November and remained very low for the remainder of the year (Figure 14).

Figure 14

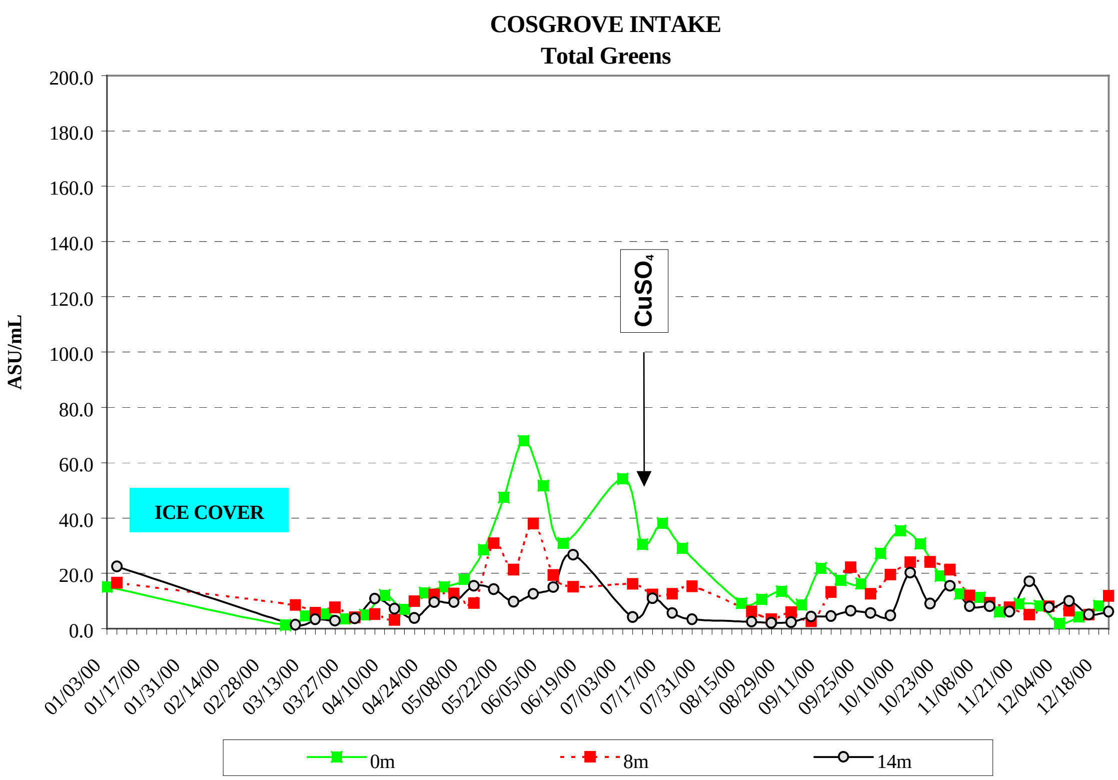
COSGROVE INTAKE
Total Bluegreens



The increasing presence of bluegreen algae during the summer is a disturbing trend. Bluegreens have been noted each summer over the past thirteen years, but concentrations generally have been low, with the exception of an annual *Anabaena* bloom. Total bluegreen algae concentrations (excluding the short bloom period for *Anabaena* in June or July) have never exceeded 100 ASU/mL prior to 1999, with summer concentrations generally between 50 and 80 ASU/mL. Total bluegreen concentrations exceeded 150 ASU/mL in 1999 and again in 2000. The colonial alga *Microcystis*, previously rare to uncommon at Wachusett, now is the most commonly found genus during the summer and fall. This could indicate the beginning of a decline in water quality and the potential for more frequent taste and odor episodes.

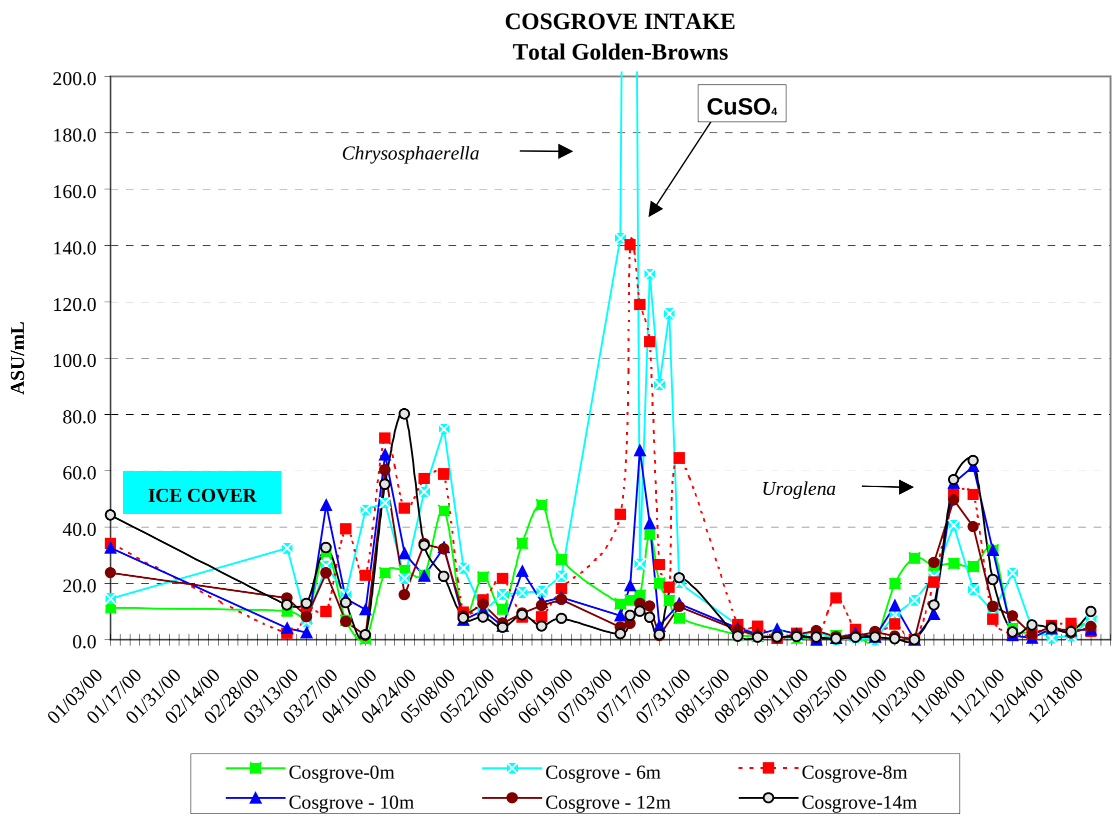
Green algae were present at all depths throughout the year, with the highest concentration (68 ASU/mL) noted at the surface at the end of May. Concentrations were below 20 ASU/mL for the first five months of the year and were only slightly higher during the remainder of 2000 (Figure 15). Green algae made up less than 15% of the total algal population except for two dates at the end of July and once during the month of October when surface samples contained 20-30% green algae.

Figure 15



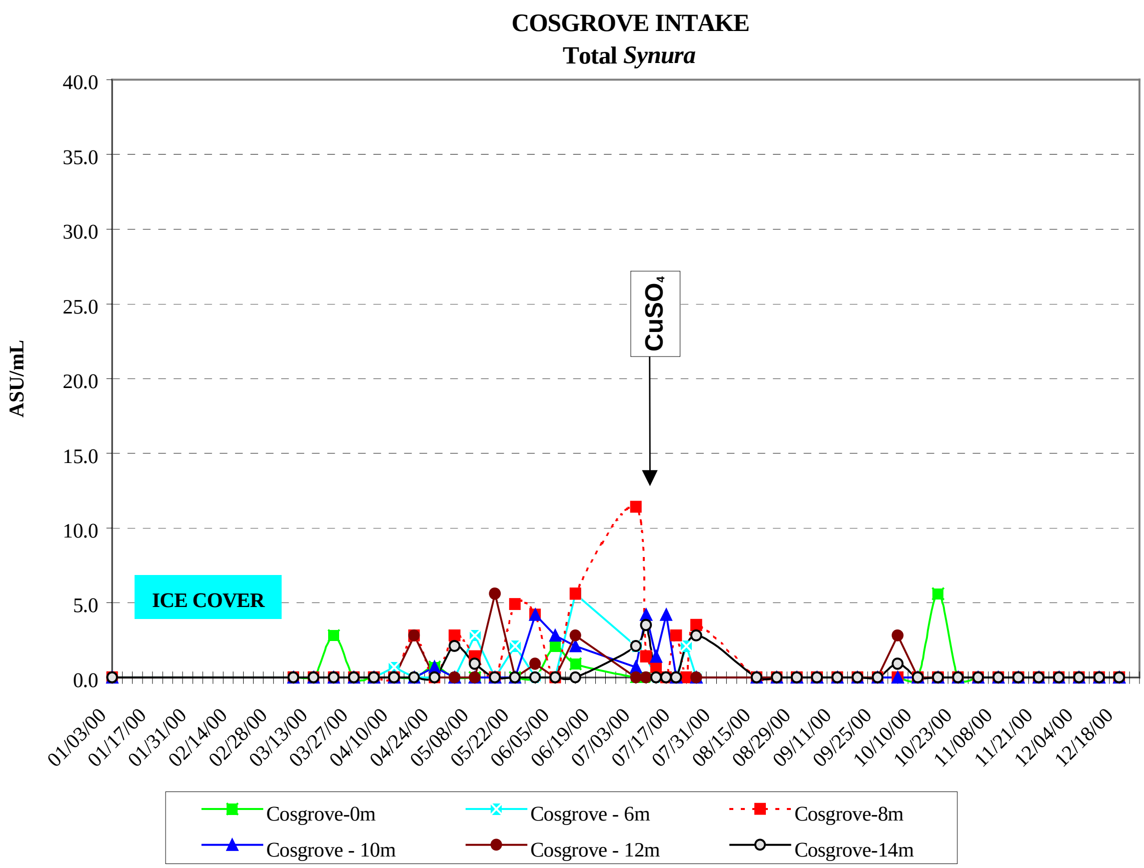
Golden-brown algae were present in low concentrations at all depths from January through June. A bloom of *Dinobryon* and *Chrysosphaerella* (at six and eight meters) took place at the beginning of July, with total golden-brown concentrations increasing from less than 30 ASU/mL to over 600 ASU/mL. (Figure 16). Numbers declined following an application of copper sulfate and were less than 10 ASU/mL by August. Golden-brown concentrations began to increase in October as *Uroglena* colonies became more common, with total concentrations exceeding 50 ASU/mL by the end of the month. Total golden-brown algae concentrations then declined and remained low (<10 ASU/mL) for the remainder of the year.

Figure 16



Synura concentrations were stable and very low throughout the year. The only time concentrations exceeded 10 ASU/mL was at eight meters in early July and the reservoir was treated with copper sulfate four days later (Figure 17). *Synura* was not expected to be a problem in 2000 as diatom concentrations in the spring were well in excess of 1000 ASU/mL. Data from the past six years seem to clearly show a link between low spring diatom concentrations and significant autumn increases of *Synura*. Competition for silica seems to play an important role in the relationship between these two groups.

Figure 17



Control of filter-clogging or taste and odor algae is difficult at certain times of the year due to inclement weather, reservoir ice cover, or because the particular species is concentrated at depth. An attempt to overcome these problems is underway. In-reservoir circulators have been proposed that would have the capability to dispense measured amounts of copper sulfate from shore directly to a predetermined depth. A pilot study of this concept has been initiated and should be operating in the summer of 2001. If the pilot is successful, the MWRA will consider the installation of a series of the circulators at the northern end of the reservoir.

A summary of nutrient and algae dynamics at the Quabbin Reservoir has just been published and is available from the MDC-DWM. This report details the scope, methods, and results of monthly sampling from October 1998 through September 1999, and also reviews historical data from the 1960s, 1980s, and 1990. A similar publication is planned for the Wachusett Reservoir.

4.0 SAMPLING PLAN

The Wachusett watershed sampling program for 2001 is a shift from the intensive and widespread monitoring done during the previous few years. Sampling activities will still include special studies, enforcement actions, incident response, and routine sampling and analysis, but the routine sampling program has been refined to focus on the effects of storm events on tributary and reservoir water quality. The program was designed to protect public health, identify current and potential threats to water quality, and further our understanding of the reservoir and its tributaries.

Fecal coliform, total coliform, and conductivity are measured weekly at twenty stations on fifteen tributaries. Monthly nutrient samples are collected from eleven tributary stations with available flow data. The stations sampled include all significant tributaries that discharge directly to the reservoir. Sampling will occur during dry weather and not within 48 hours following a rain event. A separate stormwater sampling program including all routinely sampled tributaries will also be part of the regular sampling program in order to help quantify bacterial loading to the reservoir from storm events. Tributary sampling will take place immediately following rain events (first flush) and then all stations will be resampled after 24 and 48 hours to see how long elevated fecal coliform concentrations persist after a storm. Precipitation amounts, groundwater levels, and stream flows will all be carefully documented and compared to bacteria numbers to attempt to further refine our understanding of the causes of elevated fecal coliform levels in Wachusett tributaries.

Fecal and total coliform bacteria samples are collected daily seven days per week at the Cosgrove Intake until it is determined that the threat of contamination from roosting birds no longer exists. At that time samples are collected daily Monday through Thursday. Samples for fecal and total coliform bacteria are also collected Monday through Thursday from the Route 12 bridge at the upper end of the reservoir. Monthly temperature, dissolved oxygen, pH, and conductivity profiles are taken at four reservoir stations (Cosgrove Intake, 3412, 3417, and Thomas Basin) during ice-free periods using a Hydrolab H20 Sonde Unit and a Surveyor III data logger. More frequent profiles will be collected when necessary to document changing conditions in the reservoir. Algae samples are collected one to three times a week at six depths from the Cosgrove Intake and quarterly from three additional reservoir stations. Samples for nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, total phosphorus, and silica will be collected quarterly from the four reservoir stations.

The movement of water and contaminants through the reservoir, especially during times when water is being transferred to Wachusett Reservoir from Quabbin Reservoir, has become the focus of significant interest. Sampling of the reservoir surface will continue on a regular basis. Weekly transect sampling will be done when feasible to help further understand the effect of water movement on fecal coliform levels throughout the reservoir. Some sampling at different depths may also be attempted. Sampling of total coliform in the tributaries, tributary coves, and through the reservoir following storm events are also planned for 2001.

The *Giardia* and *Cryptosporidium* sampling program was originally designed to focus on the development of baseline data in the Wachusett watershed. Samples were collected for two years at two stations on the major tributaries to the Wachusett Reservoir (the Quinapoxet and Stillwater Rivers). Samples were also collected for two years from two smaller tributaries surrounded by residential development (Gates Brook) and by wildlife habitat (French Brook). During 2001 and for the following two years a study of the movement of pathogens during storm events will be undertaken by UMASS with funding from the American Water Works Association Research Foundation and the cooperation of the MDC Division of Watershed Management. The study is designed to look at different land uses (agriculture, residential, forest) and determine how best to monitor pathogens and their movement through the watershed during both wet and dry conditions throughout the year. This information will be used to optimize future sampling programs and to more accurately predict potential public health problems.

Macroinvertebrate samples will be collected from twenty-three stations on twenty tributaries during the spring to help detect impacts of intermittent pollution events that might be missed by routine sampling programs. Population information developed from these samples will be compared with historic data collected over the last twelve years. Additional samples will be collected in the summer and fall if possible to investigate seasonal variation in Wachusett tributaries.

Sampling of the Pinecroft area drainage basin will continue in order to evaluate the impacts of sewering on water quality in a small urbanized tributary to the Wachusett Reservoir. Initial sampling has established baseline and stormwater nutrient and bacteria levels and profiled water quality within a small subbasin at the headwaters of Gates Brook prior to sewer construction. The same has been done for two additional sampling locations, one in a pristine forested watershed and one at an agricultural operation, in order to enable the Division to compare and contrast the three land uses. The multi-year study will continue during 2001 as sewer hookups are completed with weekly bacteria samples and monthly nutrient samples at three stations to monitor water quality after sewers are in the ground and to compare water quality in areas with different land uses. Additional storm sampling will also take place when feasible, with focus on collection of data during different seasonal conditions.